**NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS**

**SCHOOL OF SCIENCES**
**DEPARTMENT OF INFORMATICS AND TELECOMMUNICATIONS**
**DEPARTMENT OF ECONOMICS**

**INTERDEPARTMENTAL PROGRAM OF POSTGRADUATE STUDIES IN MANAGEMENT AND ECONOMICS OF TELECOMMUNICATION NETWORKS**


**PhD THESIS**

# Modeling the regulatory intervention in the telecommunications market


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**ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ**

# Μοντελοποίηση των ρυθμιστικών παρεμβάσεων στην τηλεπικοινωνιακή αγορά

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**ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ**

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**Μάρκος Θ. Τσελεκούνης**

**ΕΠΙΒΛΕΠΩΝ ΚΑΘΗΓΗΤΗΣ: Δημήτριος Βαρουτάς,** Επίκουρος Καθηγητής ΕΚΠΑ

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# ABSTRACT

This thesis discusses the role of sector-specific regulators in the rapidly changing telecommunications industry. In particular, it studies the access pricing policy which provides the optimal balance between static and dynamic efficiency that better reflects the changing regulatory goals in a highly variable economic and technological environment. Static efficiency concerns the maximization of social welfare by intensifying the competition for providing differentiated services (service-based competition), whereas dynamic efficiency concerns the maximization of social welfare by incentivizing investments in competitive infrastructures (facilities-based competition). It is thus obvious that the role of regulators is to facilitate the gradual transition from static to dynamic efficiency by influencing the investment and competition outcomes through the regulation of the access price. Therefore, there is an interplay between regulatory policy and technological development which leads to rapidly changing market structures and industry performance.

The first significant regulatory intervention concerns the migration from a state monopoly market to a competitive telecommunications industry which mostly took place in 1990s. Obviously, the goal of regulators was to facilitate entry by alternative operators in order to achieve static efficiency. The second substantial transition towards dynamic efficiency is related to the current regulatory goal of promoting the migration from service-based competition over the legacy copper access networks to service-based competition over the so-called fibre-based Next Generation Access (NGA) networks. This goal aims at providing significant investment incentives without distorting the subsequent competition outcomes, and hence, is related to the common trade-off between static and dynamic efficiency. Facilities-based competition is expected to resolve such trade-off, which implies that the future regulatory goal concerns the migration from service-based to facilities-based competition over NGA networks. The aim of this thesis is to model the regulatory intervention in order to derive the access pricing policy that achieves the efficiency goals of each migration phase.

The first chapter of this thesis discusses the background of the past, the present and the future state of telecommunications markets and regulation. In particular, it presents the economic and technical reasons that necessitate each migration and describes the respective regulatory goal in terms of efficiency implications. It is obvious that each migration requires a specific access pricing policy in order to achieve the optimal balance between static and dynamic efficiency. The three following chapters discuss the optimal access pricing policy that achieves the past, the current and the future regulatory goals, respectively.

In particular, the second chapter discusses the optimal access pricing policy that aims at promoting static efficiency by facilitating the migration from a state monopoly market to a competitive telecommunications industry. In this context, this chapter extensively reviews the contributed article studying the access conditions under which an entrant's decision to purchase an essential access input from the incumbent or to make the access input itself achieves static efficiency.

The third chapter discusses the regulatory goal of encouraging investments in NGA networks without distorting the subsequent competition outcomes in order to facilitate the migration from service-based competition over copper access networks to service-based competition over NGA networks. In this context, this chapter also extensively reviews the contributed articles studying: (i) the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal NGA investment level; (ii) the impact of geographic price discrimination on a monopolist's incentives to invest in

welfare-enhancing NGA investments; and (iii) a monopolist's incentives to undertake the socially optimal geographically differentiated NGA deployment.

The fourth chapter discusses the regulatory policy which aims at promoting dynamic efficiency by facilitating the migration from service-based to facilities-based competition over NGA networks. In this context, an innovative approach, which is based on the basic principles governing a Credit Default Swap (CDS), is proposed to provide an effective migration path towards facilities-based competition over NGA networks.

The last chapter of this thesis concludes the main policy implications drawn from the discussion about the past, the present and the future state of telecommunications markets and regulation, summarizes the derived research results of the contributed research articles and proposes directions for future research.

**SUBJECT AREA**: Telecommunications economics and regulation

**KEYWORDS**: access regulation, dynamic efficiency, investment incentives, next generation access (NGA) networks, static efficiency

# ΠΕΡΙΛΗΨΗ

Η παρούσα διδακτορική διατριβή μελετά το ρόλο των ρυθμιστικών αρχών σε μία συνεχώς μεταβαλλόμενη τηλεπικοινωνιακή αγορά. Πιο συγκεκριμένα, η παρούσα διατριβή μελετά τη ρυθμιζόμενη τιμολογιακή πολιτική πρόσβασης στον τοπικό βρόχο που οδηγεί στη βέλτιστη αναλογία μεταξύ στατικής και δυναμικής αποδοτικότητας, η οποία αντικατοπτρίζει με τον πλέον ικανοποιητικό τρόπο τον εκάστοτε στόχο των ρυθμιστικών αρχών σε ένα ευμετάβλητο οικονομικό και τεχνολογικό περιβάλλον. Η στατική αποδοτικότητα σχετίζεται με τη μεγιστοποίηση της κοινωνικής ευημερίας μέσω της εντατικοποίησης του επιπέδου του ανταγωνισμού για παροχή διαφοροποιημένων υπηρεσιών, ενώ η δυναμική αποδοτικότητα σχετίζεται με τη μεγιστοποίηση της κοινωνικής ευημερίας μέσω της προώθησης του ανταγωνισμού για επενδύσεις σε ανταγωνιστικές υποδομές. Είναι φανερό ότι ο ρόλος των ρυθμιστικών αρχών είναι να διευκολύνουν τη σταδιακή μετάβαση από τη στατική στη δυναμική αποδοτικότητα επηρεάζοντας τα επίπεδα επενδύσεων και ανταγωνισμού μέσω της ρύθμισης της τιμής πρόσβασης. Επομένως, υπάρχει μια αλληλεπίδραση μεταξύ της ρυθμιστικής πολιτικής και της τεχνολογικής ανάπτυξης με αποτέλεσμα τη συνεχή εναλλαγή δομών αγοράς και βιομηχανικής απόδοσης.

Η πρώτη σημαντική ρυθμιστική παρέμβαση στην τηλεπικοινωνιακή αγορά σχετίζεται με τη μετάβαση από την κρατική μονοπωλιακή αγορά σε μία πιο ανταγωνιστική που έλαβε χώρα κυρίως στα τέλη του 1990. Όπως είναι προφανές, ο στόχος των ρυθμιστικών αρχών κατά τη συγκεκριμένη μετάβαση ήταν να διευκολύνουν την είσοδο στην αγορά εναλλακτικών τηλεπικοινωνιακών παρόχων έτσι ώστε να επιτευχθεί στατική αποδοτικότητα. Η δεύτερη ουσιαστική μετάβαση προς τη δυναμική αποδοτικότητα σχετίζεται με τον τρέχων στόχο των ρυθμιστικών αρχών να προωθήσουν τη μετάβαση από τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω των χάλκινων δικτύων πρόσβασης στον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω των λεγόμενων Δικτύων Πρόσβασης Νέας Γενιάς (NGA), τα οποία χρησιμοποιούν κυρίως οπτικές ίνες για τη μετάδοση πληροφοριών. Ο συγκεκριμένος στόχος προϋποθέτει την παροχή σημαντικών κινήτρων για επενδύσεις χωρίς να διαστρεβλώνεται το επίπεδο ανταγωνισμού και επομένως σχετίζεται με τον αντικρουόμενο στόχο της ταυτόχρονης επίτευξης στατικής και δυναμικής αποδοτικότητας. Ο ανταγωνισμός για επενδύσεις σε ανταγωνιστικές υποδομές αναμένεται να οδηγήσει σε μια τέτοια ταυτόχρονη επίτευξη που σημαίνει ότι ο μελλοντικός στόχος των ρυθμιστικών αρχών είναι η μετάβαση από τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω NGA δικτύων σε ανταγωνισμό για επενδύσεις σε ανταγωνιστικές NGA υποδομές. Ο στόχος της παρούσας διδακτορικής διατριβής είναι να μοντελοποιήσει τη ρυθμιστική παρέμβαση για να προσδιορίσει την τιμολογιακή πολιτική πρόσβασης που επιτυγχάνει τους στόχους των ρυθμιστικών αρχών σε όρους αποδοτικότητας σε κάθε μεταβατική περίοδο.

Το πρώτο κεφάλαιο της διατριβής αναλύει την τηλεπικοινωνιακή αγορά και το ρόλο των ρυθμιστικών αρχών κατά το παρελθόν, το παρόν και το μέλλον. Παρουσιάζονται οι οικονομικοί και οι τεχνολογικοί λόγοι που υπαγορεύουν την κάθε μετάβαση και περιγράφονται οι αντίστοιχοι στόχοι των ρυθμιστικών αρχών σε όρους αποδοτικότητας. Αυτό συνεπάγεται ότι κάθε μεταβατική περίοδος απαιτεί μια συγκεκριμένη ρυθμιστική πολιτική πρόσβασης έτσι ώστε να επιτευχθεί η εκάστοτε κατάλληλη ισορροπία μεταξύ στατικής και δυναμικής αποδοτικότητας. Τα τρία επόμενα κεφάλαια που ακολουθούν περιγράφουν τη βέλτιστη ρυθμιστική πολιτική που επιτυγχάνει τον παρελθοντικό, τον τρέχων και τον μελλοντικό, αντίστοιχα, στόχο των ρυθμιστικών αρχών.

Πιο συγκεκριμένα, το δεύτερο κεφάλαιο περιγράφει τη βέλτιστη ρυθμιστική πολιτική που στοχεύει στην προώθηση της στατικής αποδοτικότητας μέσω της μετάβασης από την

πρώην κρατική μονοπωλιακή τηλεπικοινωνιακή αγορά σε μία πιο ανταγωνιστική αγορά. Επίσης, αναλύεται εκτενώς η συνεισφορά της παρούσας διατριβής στο συγκεκριμένο ρυθμιστικό πλαίσιο μέσω ενός άρθρου που εξετάζει τις συνθήκες πρόσβασης κάτω από τις οποίες η απόφαση ενός εναλλακτικού παρόχου να νοικιάσει το δίκτυο πρόσβασης του πρώην κρατικού (κατεστημένου) παρόχου ή να χρησιμοποιήσει τις ιδιόκτητες δικτυακές υποδομές επιτυγχάνει στατική αποδοτικότητα.

Το τρίτο κεφάλαιο αναλύει το στόχο των ρυθμιστικών αρχών να ενθαρρύνουν τις επενδύσεις σε NGA δίκτυα χωρίς να διαστρεβλώσουν το επίπεδο ανταγωνισμού προωθώντας τη μετάβαση από τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω των χάλκινων δικτύων πρόσβασης στον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω NGA δικτύων. Υπό αυτό το πρίσμα, αναλύεται εκτενώς η συνεισφορά της παρούσας διατριβής μέσω των άρθρων που εξετάζουν: (i) την επίδραση της ρυθμιστικής αβεβαιότητας στα κίνητρα ενός κατεστημένου παρόχου να αναλάβει το κοινωνικά επιθυμητό επίπεδο επένδυσης σε NGA δίκτυα, (ii) την επίδραση της γεωγραφικά διαφοροποιημένης τιμολόγησης των υπηρεσιών λιανικής στα κίνητρα ενός μονοπωλητή να επενδύσει σε NGA υποδομές που αυξάνουν την κοινωνική ευημερία, και (iii) τα κίνητρα ενός μονοπωλητή να αναπτύξει το κοινωνικά βέλτιστο γεωγραφικά διαφοροποιημένο (σε όρους ποιότητας) NGA δίκτυο.

Το τέταρτο κεφάλαιο περιγράφει τη βέλτιστη ρυθμιστική πολιτική που στοχεύει στην επίτευξη δυναμικής αποδοτικότητας μέσω της προώθησης της μετάβασης από τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω NGA δικτύων σε ανταγωνισμό για επενδύσεις σε ανταγωνιστικές NGA υποδομές. Μέσα σε αυτό το πλαίσιο, προτάθηκε μία ολοκληρωμένη προσέγγιση που αντιπροσωπεύει ένα αποτελεσματικό μεταβατικό μονοπάτι προς την επίτευξη του ανταγωνισμού για επενδύσεις σε ανταγωνιστικές NGA υποδομές. Η καινοτομία της συγκεκριμένης προσέγγισης έγκειται στο γεγονός ότι βασίζεται στην εφαρμογή των βασικών αρχών ενός αμιγώς χρηματοοικονομικού εργαλείου, των Credit Default Swaps, στην τηλεπικοινωνιακή αγορά.

Το τελευταίο κεφάλαιο συνοψίζει τις κύριες ρυθμιστικές προεκτάσεις που εξάγονται από τη συζήτηση σχετικά με το παρελθόν, το παρόν και το μέλλον των τηλεπικοινωνιακών αγορών και της ρυθμιστικής πολιτικής, παρουσιάζει συνοπτικά τα εξαγόμενα αποτελέσματα από τη συνεισφορά της παρούσας διατριβής μέσω των άρθρων που συνεισφέρουν στη σχετική βιβλιογραφία και δίνει τις κατευθυντήριες γραμμές για μελλοντική έρευνα.

**ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ**: Οικονομική και ρύθμιση των τηλεπικοινωνιών

**ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ**: ρύθμιση πρόσβασης, δυναμική αποδοτικότητα, επενδυτικά κίνητρα, δίκτυα πρόσβασης επόμενης γενιάς (NGA), στατική αποδοτικότητα

*Στη μνήμη του φίλου μου Γιάννη*

# ΕΥΧΑΡΙΣΤΙΕΣ

Η Ελληνική γλώσσα φαντάζει τόσο φτωχή για να μπορέσω να αποδώσω με λέξεις τον ορισμό της διαδικασίας εκπόνησης μιας διδακτορικής διατριβής. Αν έπρεπε όμως να δώσω έναν ορισμό θα επέλεγα τον εξής: «η μοναχική δοκιμασία για την επίτευξη ενός κινούμενου στόχου». Μοναχική, γιατί τα όσα βιώνεις δε μπορούν να γίνουν κατανοητά από τον όποιο περίγυρό σου, όσο πρόθυμοι και αν είναι οι άνθρωποι που σε αγαπούν και νοιάζονται πραγματικά για εσένα˙ δοκιμασία, γιατί η εναλλαγή συναισθημάτων είναι τόσο έντονη και γρήγορη που η συγκέντρωση στο στόχο φαντάζει πράξη άξια θαυμασμού˙ κινούμενος στόχος, γιατί σε ένα τόσο ευμετάβλητο οικονομικό και τεχνολογικό περιβάλλον, ο στόχος που έχεις εξ' αρχής θέσει μετακινείται και προσαρμόζεται κάνοντας την επίτευξή του να μοιάζει με σκοτεινό λαβύρινθο. Όσο όμως μοναχική κι αν είναι η δοκιμασία για την επίτευξη αυτού του στόχου, υπάρχουν κάποιοι άνθρωποι που χτίζουν γύρω σου τοίχους και οδοφράγματα για να μπορέσεις να επικεντρωθείς στον κινούμενο στόχο σου και τους οποίους οφείλω να ευχαριστήσω.

Δε μπορώ να μη ξεκινήσω από την οικογένειά μου, και να εστιάσω περισσότερο στους γονείς μου, Αγγελική και Θάνο, που απλόχερα μου προσφέρουν ανιδιοτελώς όλα όσα απαιτούνται για να ικανοποιήσω τις προσωπικές μου φιλοδοξίες. Όμως, ότι πιο σημαντικό μου έχουν χαρίσει είναι η στάση ζωής απέναντι σε οτιδήποτε *θεωρείται* μοναδικό και αληθινό. Μου έμαθαν να αγωνίζομαι για την αλήθεια και τη γνώση, στοιχεία απαραίτητα για τη συνεισφορά στην αυθεντικότητα της επιστήμης. Ελπίζω να σας κάνω περήφανους κάθε μέρα.

Ύστερα… οι δάσκαλοί μου. Όλοι όσοι πίστεψαν στις δυνατότητές μου και μου έδωσαν δικαίωμα στο όνειρο. Τα λόγια είναι φτωχά για να εκφράσω τις ευχαριστίες μου στους Καθηγητές Δ.Μαρτάκο, Ν.Βερναρδάκη και Ι.Γιαννέλη για την αμέριστη υποστήριξη που μου χαρίσανε και που ήταν δίπλα μου καθ' όλη τη διάρκεια της εκπόνησης της διδακτορικής μου διατριβής θυσιάζοντας μεγάλο μέρος από τον προσωπικό τους ελεύθερο χρόνο. Ένα μεγάλο ευχαριστώ στους Καθηγητές Ν.Βέττα και Ι.Κατσουλάκο, δύο από τους πλέον δραστήριους ερευνητικά οικονομολόγους, που μου έκαναν την τιμή να είναι μέλη της επταμελούς εξεταστικής επιτροπής της διατριβής μου. Επίσης, θα ήθελα να ευχαριστήσω τον Επίκουρο Καθηγητή Ε.Αθανασίου για το ήθος που μου δίδαξε και την προθυμία του να παρέχει τις συμβουλές του κάθε φορά που μου ήταν απαραίτητες. Τέλος, το πιο μεγάλο ευχαριστώ στον Άνθρωπο, Φίλο και Καθηγητή μου, Δημήτρη Βαρουτά, που μοιραστήκαμε τις χαρές, τις λύπες, τα χαμόγελα και τις απογοητεύσεις, απόρροια των αποτελεσμάτων της πορείας της διατριβής. Τον ευχαριστώ γιατί εκτός από καθοδηγητής, υπήρξε και συμβουλάτορας σε μια σειρά θεμάτων που δεν άπτονται της επιστημονικής έρευνας. Εύχομαι να έχω την τύχη να συνεργάζομαι πάντα με τέτοιους Καθηγητές, και πολύ περισσότερο Ανθρώπους.

Έπειτα… οι φίλοι και οι συνεργάτες μου. Δυστυχώς, ο Θεός δε μου χάρισε ένα αδερφάκι, όμως μου έστειλε απλόχερα στο διάβα μου φίλους αληθινούς που ξέρω ότι νοιάζονται πραγματικά για εμένα, χαίρονται με τις χαρές μου και λυπούνται με τις λύπες μου. Δε θα ήθελα να κάνω καμία αναφορά σε ονόματα γιατί πραγματικά θα ήταν άδικο για τους υπόλοιπους. Απλώς, ιδιαίτερη μνεία θα κάνω στο φίλο μου Νίκο Χοστελίδη, όχι γιατί ξεχωρίζει από όλους τους υπόλοιπους, αλλά για τις ατέλειωτες ώρες συζητήσεων που κάναμε σχετικά με τα ερευνητικά μου ενδιαφέροντα και τη πορεία του διδακτορικού μου. Τον ευχαριστώ για τις ώρες που αφιέρωσε να διαβάζει θέματα που δεν άπτονται της καθημερινής του ενασχόλησης για να μου προτείνει βελτιώσεις και λύσεις. Επίσης, θα ήθελα να ευχαριστήσω όλους τους ερευνητές στο Τμήμα Πληροφορικής και Τηλεπικοινωνιών που είχα την τιμή να τους γνωρίσω και να συνεργαστώ μαζί τους. Δεν θα μπορούσα να μην κάνω μία ξεχωριστή αναφορά στον συνεργάτη, μα πάνω από όλα φίλο, Δημήτρη Μανιαδάκη για τις ατέλειωτες ώρες συζητήσεων σχετικά με ερευνητικά και όχι μόνο θέματα. Φίλε Δημήτρη, αν δεν είχα εσένα σε όλες τις δύσκολες στιγμές απομόνωσης που ένιωσα κατά τη διάρκεια της εκπόνησης της διατριβής, ίσως να ήμουν ακόμα Υποψήφιος Διδάκτορας.

Το τελευταίο και το πιο μεγάλο ευχαριστώ το κράτησα για έναν άνθρωπο που εδώ και εφτά χρόνια μοιράζομαι τις πιο όμορφες στιγμές μου. Είναι ο άνθρωπος που στέκεται δίπλα μου σε κάθε δύσκολη στιγμή και μου απλώνει ένα πέπλο αγάπης για να με προστατεύει από οτιδήποτε μπορεί να με βλάψει. Είναι ο άνθρωπος που μου δωρίζει την πιο ζεστή αγκαλιά του για να με γαληνέψει και να μου χαρίσει την απόλυτη ψυχική ηρεμία που χρειάζεται για την εκπόνηση μίας διδακτορικής διατριβής. Είναι ο άνθρωπος και συνοδοιπόρος αυτής της διαδρομής που καρτερικά περιμέναμε το τέλος της. Και να που φτάσαμε... Στελλίτσα μου, δε βρίσκω τα λόγια να σε ευχαριστήσω… σου χαρίζω το μερίδιο επιτυχίας που σου αναλογεί.

Δε θα πρέπει να λησμονήσω να αναφέρω το γεγονός ότι η παρούσα έρευνα συγχρηματοδοτήθηκε από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο - ΕΚΤ) και από εθνικούς πόρους μέσω του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» του Εθνικού Στρατηγικού Πλαισίου Αναφοράς (ΕΣΠΑ) – Ερευνητικό Χρηματοδοτούμενο Έργο: Ηράκλειτος ΙΙ . Επένδυση στην κοινωνία της γνώσης μέσω του Ευρωπαϊκού Κοινωνικού Ταμείου. Ευχαριστώ όλους τους φορείς που συνέβαλλαν στην οικονομική μου σταθερότητα κατά τη διάρκεια της εκπόνησης της παρούσας διατριβής καθιστώντας έτσι δυνατή την απρόσκοπτη συγκέντρωση μου στην ολοκλήρωσή της.

# LIST OF PUBLICATIONS

## A. Publications as part of the thesis

A.1. International Journals

i) M. Tselekounis and D. Varoutas, “Investments in next generation access infrastructures under regulatory uncertainty,” *Telecommunications Policy*, vol. 37, no. 10, pp. 879–892, Nov. 2013.

ii) M. Tselekounis, D. Varoutas, and D. Martakos, “On the social optimality of make-or-buy decisions,” *Journal of Regulatory Economics*, vol. 41, no. 2, pp. 238–268, Sep. 2012.

A.2. International Conferences

iii) M. Tselekounis, E. Xylogianni, D. Varoutas, and D. Martakos, “Geographically differentiated NGA deployment,” accepted in *24th European Regional Conference of the International Telecommunications Society (ITS), 20-23 October 2013, Florence, Italy*.

iv) M. Tselekounis, D. Maniadakis, and D. Varoutas, “NGA investment incentives under geographic price discrimination,” in *40th EARIE Conference, 30 August-1 September 2013, Évora, Portugal*.

v) M. Tselekounis, D. Varoutas, and D. Martakos, “On the irrelevance of input prices from a regulatory perspective,” *in 5th International conference on competition and regulation (CRESSE), 2-4 July 2010, Chania, Greece*.

A.3. Submitted to International Journals

vi) M. Tselekounis, D. Varoutas, and D. Martakos, “A CDS approach to induce facilities-based competition over NGA networks,” *submitted to Telecommunications Policy* (under 3rd round revision), 2013.

## B. Additional publications

B.1 International Journals

vii) D. Katsianis, T. Rokkas, I. Neokosmidis, M. Tselekounis, D. Varoutas, I. Zacharopoulos, and A. Bartzoudi, “Risks associated with next generation access networks investment scenarios,” *IEEE Network*, vol. 26, no. 4, pp. 11–17, 2012.

B.2. International Conferences

viii) M. Tselekounis, D. Maniadakis, and D. Varoutas, “NGA investments: A departure from the existing cost and demand structure assumptions,” in *19th ITS Biennial Conference, November 2012, Bangkok , Thailand*.

ix) M. Tselekounis and D. Varoutas, “Modeling the regulatory uncertainty of NGA investments under cost-based access rules,” in *7th International Conference on Competition and Regulation (CRESSE), July 2012, Chania, Greece*.

x) M. Tselekounis and D. Varoutas, “Two-way interconnection , competition and investment incentives : A survey of the economic literature,” in *11th Conference of Telecommunication, Media and Interet Techno-Economics (CTTE), June 2012, Athens, Greece*.

xi) M. Tselekounis, D. Varoutas, and D. Martakos, “Flexibility or certainty? A regulatory dilemma,” in *4th Annual Conference of Competition and Regulation in Network Industries (CRNI), November 2011, Brussels, Belgium*.

xii) M. Tselekounis, D. Varoutas, and D. Martakos, “Access Pricing Under Stackelberg Competition : Results Interpretation and Regulatory Implications,” in *8th Conference of Telecommunication, Media and Internet Techno-Economics (CTTE), June 2009, Stockholm, Sweden*.

# ΣΥΝΟΠΤΙΚΗ ΠΑΡΟΥΣΙΑΣΗ ΤΗΣ ΔΙΔΑΚΤΟΡΙΚΗΣ ΔΙΑΤΡΙΒΗΣ

Ένα τηλεπικοινωνιακό δίκτυο αποτελείται από δύο μεγάλα υποδίκτυα, τα οποία είναι σε άμεση αλληλεπίδραση για την παροχή των τηλεπικοινωνιακών υπηρεσιών στους τελικούς χρήστες. Το πρώτο αφορά το δίκτυο κορμού, το οποίο ενώνει τα αστικά κέντρα ενός τηλεπικοινωνιακού παρόχου μεταξύ τους, ενώ το δεύτερο αφορά το δίκτυο πρόσβασης, το οποίο ενώνει τις τερματικές οικιακές συσκευές με το πλησιέστερο αστικό κέντρο. Σε ολόκληρο τον αναπτυγμένο κόσμο, τα τηλεπικοινωνιακά δίκτυα αναπτύχθηκαν με κρατικές δαπάνες και αποτελούνταν εξ' ολοκλήρου από χάλκινα καλώδια τα οποία επέτρεπαν την παροχή υπηρεσιών φωνής. Επομένως, τόσο η ιδιοκτησία του δικτύου όσο και η παροχή τηλεπικοινωνιακών υπηρεσιών ασκούνταν από κρατικούς φορείς.

Η απελευθέρωση της αγοράς τηλεπικοινωνιών και η ιδιωτικοποίηση των τηλεπικοινωνιακών παρόχων που έλαβε χώρα στις ΗΠΑ και στη Μεγάλη Βρετανία στις αρχές τις δεκαετίας του 1980 και στην υπόλοιπη Ευρώπη στα τέλη της δεκαετίας του 1990, ήταν αποτέλεσμα της επικρατούσας αντίληψης ότι ο ανταγωνισμός οδηγεί σε βελτίωση της κοινωνικής ευημερίας σε σχέση με το μονοπώλιο. Το μείζον πρόβλημα που προέκυψε κατά την μετάβαση από την πρώην μονοπωλιακή αγορά σε μία ολιγοπωλιακή ήταν οι τεράστιες ασυμμετρίες μεταξύ του πρώην κρατικού μονοπωλητή/ κατεστημένου παρόχου (incumbent) και των δυνητικών νεοεισερχόμενων παρόχων (new entrants). Η κύρια ασυμμετρία αφορούσε την ιδιοκτησία του δικτύου, καθώς οι νεοεισερχόμενοι πάροχοι θα έπρεπε να επενδύσουν σε ιδιόκτητες δικτυακές υποδομές ή να ζητήσουν πρόσβαση σε αυτές του κατεστημένου παρόχου. Στην πρώτη περίπτωση, οι νεοεισερχόμενοι πάροχοι θα έπρεπε να αναπτύξουν ιδιόκτητα δίκτυα κορμού και πρόσβασης. Παρόλα αυτά, η ανάπτυξη δικτύων πρόσβασης είναι εξαιρετικά κοστοβόρα και πολλές φορές μη κοινωνικά επιθυμητή επειδή εμφανίζει χαρακτηριστικά φυσικού μονοπωλίου λόγω των σημαντικών οικονομιών πυκνότητας που ενέχουν. Στη δεύτερη περίπτωση, ο κατεστημένος πάροχος θα μπορούσε να απαιτήσει ένα εξαιρετικά υψηλό τίμημα για την ενοικίαση των υποδομών του έτσι ώστε να διατηρήσει τη μονοπωλιακή του θέση. Για τους παραπάνω λόγους, η λύση που προτάθηκε ήταν η υποχρεωτική ενοικίαση του δικτύου πρόσβασης στους εναλλακτικούς παρόχους σε ρυθμιζόμενες από την εκάστοτε Εθνική Ρυθμιστική Αρχή (ΕΡΑ) τηλεπικοινωνιών τιμές. Η συγκεκριμένη ρυθμιστική πρακτική είναι ευρέως γνωστή ως αδεσμοποίητη πρόσβαση στον τοπικό βρόχο (Local Loop Unbundling – LLU).

Παρόλα αυτά, οι συνθήκες κάτω από τις οποίες θα εφαρμοζόταν η μετάβαση από το μονοπώλιο στο ολιγοπώλιο οδήγησε σε μία έντονη διαμάχη με κεντρικό περιεχόμενο τη βέλτιστη τιμή πρόσβασης που θα εξυπηρετούσε τους στόχους των ρυθμιστικών αρχών. Πιο συγκεκριμένα, οι κύριοι στόχοι κάθε ρυθμιστικής παρέμβασης είναι να: (i) επιτύχει στατική αποδοτικότητα (static efficiency) που συνεπάγεται μεγαλύτερο πλεόνασμα καταναλωτή μέσω χαμηλότερων τιμών και καλύτερης ποιότητας υπηρεσιών, και (ii) την επίτευξη δυναμικής αποδοτικότητας (dynamic efficiency) που συνεπάγεται οικονομική μεγέθυνση και καινοτομία μέσω παροχής κινήτρων για την ανάληψη του κοινωνικά βέλτιστου ύψους επενδύσεων σε προηγμένες δικτυακές υποδομές.

Η στατική αποδοτικότητα σχετίζεται με τη μείωση της ισχύος του κατεστημένου παρόχου έτσι ώστε να προωθηθεί η είσοδος εναλλακτικών παρόχων στην αγορά και να εντατικοποιηθεί ο μεταξύ τους ανταγωνισμός για παροχή καλύτερων και (οριζοντίως) διαφοροποιημένων υπηρεσιών (service-based competition). Αυτού του είδους ο ανταγωνισμός προωθεί τόσο τη βέλτιστη χρησιμοποίηση των πόρων (productive efficiency) όσο και τη βέλτιστη κατανομή τους στην κοινωνία (allocative efficiency), προωθώντας έτσι την επίτευξη στατικής αποδοτικότητας. Αντίθετα, η δυναμική αποδοτικότητα σχετίζεται με τον μακροπρόθεσμο στόχο της ρυθμιστικής πολιτικής για την ενθάρρυνση των παρόχων να επενδύσουν σε ανταγωνιστικές δικτυακές υποδομές που θα οδηγήσει σε έναν αέναο ανταγωνισμό για παροχή καινοτόμων και ποιοτικά διαφοροποιημένων υπηρεσιών (facilities-based competition). Αυτού του είδους ο ανταγωνισμός μεγιστοποιεί τα οφέλη για τον καταναλωτή καθώς οδηγεί σε μεγιστοποίηση της κοινωνικής ευημερίας, μεγιστοποίηση της οικονομικής ανάπτυξης και ελαχιστοποίηση του κόστους παραγωγής. Καθίσταται έτσι σαφές ότι η επίτευξη τόσο στατικής όσο και δυναμικής αποδοτικότητας μπορεί να είναι ένας εφικτός στόχος μακροπρόθεσμα. Βραχυπρόθεσμα όμως, η προώθηση της εισόδου αποδοτικών παρόχων στην αγορά μέσω της LLU ρυθμιστικής πρακτικής δημιουργεί μια αρνητική συσχέτιση μεταξύ των δύο βασικών στόχων της ρυθμιστικής πολιτικής.

Κατά τη δημιουργία ενός ανταγωνιστικού περιβάλλοντος ήταν αναμενόμενο η ρυθμιστική πολιτική να επικεντρωθεί στην προώθηση του service-based competition, καθώς η προώθηση του facilities-based competition είναι ένας μακροπρόθεσμος στόχος που προϋποθέτει μια ισχυρή πελατειακή βάση για τους νεοεισερχόμενους παρόχους. Η τιμολογιακή πολιτική που εφαρμόστηκε ήταν η επιβολή κοστοστρεφών τιμών πρόσβασης (cost-based access prices), δηλαδή η τιμή πρόσβασης ορίστηκε ίση με το οριακό κόστος της παροχής πρόσβασης. Εκτός από την απλότητα της συγκεκριμένης τιμολογιακής πολιτικής, το κύριο επιχείρημα υπέρ της κοστοστρεφούς τιμολόγησης ήταν ότι παρέχει στους νεοεισερχόμενους παρόχους τα κατάλληλα κίνητρα για να λάβουν την productively efficient απόφαση σχετικά με την ενοικίαση του δικτύου πρόσβασης από τον κατεστημένο πάροχο ή τη χρησιμοποίηση ιδιόκτητων υποδομών πρόσβασης (make-or-buy decision). Όντως, η σχετική βιβλιογραφία συμπεραίνει ότι ενώ το μοντέλο ανταγωνισμού που περιγράφει τη δομή της αγοράς διαδραματίζει σημαντικό ρόλο στην αποτελεσματικότητα της τιμής πρόσβασης να οδηγήσει έναν νεοεισερχόμενο πάροχο να λάβει τη make-or-buy απόφαση που βελτιστοποιεί τη χρησιμοποίηση των πόρων, η κοστοστρεφής τιμολόγηση οδηγεί πάντα στην παραγωγικά βέλτιστη make-or-buy απόφαση ανεξαρτήτως του μοντέλου ανταγωνισμού.

Παρόλα αυτά, είναι ευρέως γνωστό από τη σχετική βιβλιογραφία ότι η βέλτιστη χρησιμοποίηση των πόρων δεν συνεπάγεται απαραίτητα και τη βέλτιστη κατανομή τους. Με άλλα λόγια, η βέλτιστη χρησιμοποίηση των πόρων είναι απαραίτητη, αλλά όχι και ικανή, συνθήκη για την επίτευξη στατικής αποδοτικότητας. Η παρούσα διδακτορική διατριβή συνεισφέρει στη βιβλιογραφία που εξετάζει τη βέλτιστη ρυθμιστική πολιτική που επιτυγχάνει τον παρελθοντικό στόχο των ρυθμιστικών αρχών να επιτύχουν στατική αποδοτικότητα κατά τη μετάβαση από την πρώην μονοπωλιακή αγορά σε μια ανταγωνιστική αγορά για την παροχή διαφοροποιημένων υπηρεσιών. Συγκεκριμένα, η παρούσα διατριβή εξετάζει τον αντίκτυπο της δομής της αγοράς στην αποτελεσματικότητα της τιμής πρόσβασης να οδηγήσει έναν νεοεισερχόμενο πάροχο να λάβει τη make-or-buy απόφαση που βελτιστοποιεί όχι μόνο τη χρησιμοποίηση αλλά και τη κατανομή των πόρων, δηλαδή οδηγεί σε στατική αποδοτικότητα. Το κύριο συμπέρασμα από τη συγκεκριμένη μελέτη είναι ότι η τιμή πρόσβασης που οδηγεί έναν νεοεισερχόμενο πάροχο να λάβει την make-or-buy απόφαση που βελτιστοποιεί τη χρησιμοποίηση των πόρων, μπορεί να οδηγήσει και σε βελτιστοποίηση της κατανομής τους αναλόγως το μοντέλο ανταγωνισμού που περιγράφει τη δομή της αγοράς. Παρόλα αυτά, η κοστοστρεφής τιμολόγηση οδηγεί πάντα σε make-or-buy αποφάσεις που επιτυγχάνουν στατική αποδοτικότητα.

Η παραπάνω ανάλυση αποδεικνύει ότι η επιλογή των ΕΡΑ να υποχρεώσουν τον κατεστημένο πάροχο να παρέχει στους αντίστοιχους νεοεισερχόμενους πρόσβαση στο δίκτυό του σε κοστοστρεφείς τιμές επιτυγχάνει τον παρελθοντικό βραχυπρόθεσμό στόχο των ρυθμιστικών αρχών κατά τη μετάβαση από το πρώην κρατικό μονοπώλιο σε ανταγωνισμό για την παροχή υπηρεσιών. Παράλληλα με την απελευθέρωση της αγοράς των τηλεπικοινωνιών, η τεχνολογική πρόοδος οδήγησε στη σταδιακή μετάβαση από την αναλογική στη ψηφιακή μετάδοση πληροφοριών. Στην πραγματικότητα, τόσο οι κατεστημένοι όσο και οι εναλλακτικοί πάροχοι δημιούργησαν ένα δίκτυο κορμού βασισμένο σε οπτικές ίνες, οπότε και έγινε τεχνικά και εμπορικά διαθέσιμη η παροχή ευρυζωνικής πρόσβασης στο διαδίκτυο σε συνδυασμό με την παροχή υπηρεσιών φωνής. Η μεγάλη απήχηση του διαδικτύου και η συνεχώς αυξανόμενη ζήτηση για υπηρεσίες που απαιτούν μεγαλύτερες ταχύτητες σύνδεσης στο διαδίκτυο, και επομένως μεγαλύτερο εύρος ζώνης, έχουν καταστήσει το χάλκινο δίκτυο πρόσβασης αδύνατο να εξυπηρετήσει την αυξανόμενη ζήτηση, καθώς τα χάλκινα δίκτυα έχουν περιορισμένες δυνατότητες σε εύρος ζώνης. Για αυτόν το λόγο οι τηλεπικοινωνιακοί πάροχοι έχουν στρέψει το ενδιαφέρον τους στη δημιουργία Δικτύων Πρόσβασης Νέας Γενιάς (NGA) που σχετίζονται με την μερική ή ολική αντικατάσταση του χάλκινου δικτύου πρόσβασης από οπτικά στοιχεία. Είναι φανερό ότι όσο μεγαλύτερο μέρος του χάλκινου δικτύου πρόσβασης αντικαθίσταται από οπτικά στοιχεία, τόσο μεγαλύτερες είναι οι εν δυνάμει προσφερόμενες ευρυζωνικές ταχύτητες πρόσβασης στο διαδίκτυο. Ταυτόχρονα, και οι εθνικές κυβερνήσεις έχουν στρέψει το ενδιαφέρον τους στις επενδύσεις σε NGA δίκτυα, καθώς έχει αποδειχθεί εμπειρικά ότι οι επενδύσεις σε τηλεπικοινωνιακές υποδομές οδηγούν σε οικονομική ανάπτυξη και δημιουργία θέσεων εργασίας. Τις παραπάνω θέσεις ασπάζεται και η Ευρωπαϊκή Επιτροπή δηλώνοντας ότι οι επενδύσεις σε NGA δίκτυα δημιουργούν κοινωνικά οφέλη που υπερβαίνουν κατά πολύ τα ιδιωτικά κίνητρα ανάπτυξης NGA δικτύων.

Παρόλα αυτά, οι τηλεπικοινωνιακοί πάροχοι είναι εξαιρετικά επιφυλακτικοί όσον αφορά την ανάπτυξη NGA δικτύων λόγω: (i) του εξαιρετικά υψηλού κόστους ανάπτυξης NGA δικτύων, (ii) της εξαιρετικά αβέβαιης ζήτησης για τις νέες υπερ-ευρυζωνικές υπηρεσίες που θα παρέχονται μέσω των NGA δικτύων, και (iii) της αδυναμίας των ρυθμιστικών αρχών να δεσμευτούν για τη μελλοντική τους ρυθμιστική πολιτική σχετικά με την πρόσβαση στα NGA δίκτυα. Από τα παραπάνω, καθίσταται σαφές ότι οι ρυθμιστικές αρχές διαδραματίζουν έναν πάρα πολύ σημαντικό ρόλο, τόσο στη δημιουργία των κατάλληλων κινήτρων για την ανάπτυξη NGA δικτύων, όσο και στην εντατικοποίηση του ανταγωνισμού για παροχή διαφοροποιημένων υπηρεσιών. Επομένως, ο τρέχων στόχος των ρυθμιστικών αρχών είναι να προωθήσουν τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών που θα διατίθενται μέσω των NGA δικτύων.

Επιστημονικές μελέτες έχουν αποδείξει (τόσο σε θεωρητικό όσο και σε εμπειρικό επίπεδο) ότι η κοστοστρεφής τιμολόγηση της πρόσβασης στα NGA δίκτυα δε μπορεί να επιτύχει το διπλό στόχο των ρυθμιστικών αρχών της ενθάρρυνσης των επενδύσεων και της προώθησης του ανταγωνισμού. Ο λόγος είναι ότι οι κατεστημένοι πάροχοι δεν είναι διατεθειμένοι να επενδύσουν σε δικτυακές υποδομές αν γνωρίζουν ότι θα είναι υποχρεωμένοι να παρέχουν τις υπηρεσίες τους στους εναλλακτικούς παρόχους σε κοστοστρεφείς τιμές, καθώς σε αυτήν την περίπτωση δε θα μπορούν να ανακτήσουν την ιδιωτική τους επένδυση. Επίσης, οι εναλλακτικοί πάροχοι δεν είναι διατεθειμένοι να επενδύσουν σε NGA δίκτυα γιατί, αν γνωρίζουν ότι θα έχουν πρόσβαση σε κοστοστρεφείς τιμές, θα περιμένουν τον κατεστημένο πάροχο να αναπτύξει NGA δίκτυα και μετά να ζητήσουν πρόσβαση, αποφεύγοντας έτσι το τεράστιο κόστος της επένδυσης. Αυτό πρακτικά σημαίνει ότι οι δύο στόχοι των ρυθμιστικών αρχών είναι σε μεγάλο βαθμό αντικρουόμενοι και σχετίζονται με την αρνητική συσχέτιση μεταξύ στατικής και δυναμικής αποδοτικότητας. Για αυτόν το λόγο, η βέλτιστη ρυθμιστική πολιτική που πρέπει να εφαρμοστεί για την προώθηση των επενδύσεων και τη διασφάλιση ενός ικανοποιητικού επιπέδου ανταγωνισμού συγκαταλέγεται ανάμεσα στα πιο επίκαιρα και αμφιλεγόμενα θέματα συζήτησης μεταξύ ακαδημαϊκών, ρυθμιστικών αρχών και πολιτικών.

Πιο συγκεκριμένα, η αδυναμία της κοστοστρεφούς τιμολόγησης να εκπληρώσει το διττό στόχο των ρυθμιστικών αρχών έχει στρέψει το ερευνητικό ενδιαφέρον στην ανεύρεση νέων ρυθμιστικών πρακτικών που θα επιτυγχάνουν καλύτερα αποτελέσματα σε όρους επενδύσεων και ανταγωνισμού από την υποχρεωτική παροχή πρόσβασης σε κοστοστρεφείς τιμές. Επομένως, η απόκλιση από τις ρυθμιστικές πρακτικές που εφαρμόστηκαν κατά τη μετάβαση από το μονοπώλιο στον ανταγωνισμό μπορεί να πάρει τρεις διαφορετικές μορφές:

- Απόκλιση σε όρους τιμολογιακής πολιτικής πρόσβασης, δηλαδή απόκλιση από τις κοστοστρεφείς τιμές. Είναι φανερό ότι όσο μεγαλύτερη η τιμή πρόσβασης, τόσο μεγαλύτερα τα κίνητρα για ανάληψη επενδύσεων, αλλά και μεγαλύτερη η στρέβλωση της αγοράς σε όρους ανταγωνισμού. Για αυτό το λόγο, η Ευρωπαϊκή Επιτροπή συστήνει την παροχή πρόσβασης σε NGA δίκτυα σε τιμές κόστους προσαυξημένες κατά ένα ποσοστό που θα αποζημιώνει τον επενδυτή για όλους τους κινδύνους που ενέχουν οι επενδύσεις σε NGA δίκτυα και μπορούν να ποσοτικοποιηθούν.
- Απόκλιση σε όρους ρυθμιστικού καθεστώτος, δηλαδή απόκλιση από το καθεστώς παροχής υποχρεωτικής πρόσβασης. Τα εναλλακτικά ρυθμιστικά καθεστώτα που έχουν προταθεί αφορούν: (i) τη μη επιβολή υποχρεωτικής πρόσβασης (regulatory forbearance), (ii) τη μη επιβολή υποχρεωτικής πρόσβασης για ένα χρονικό διάστημα και έπειτα την επιβολή πρόσβασης σε ρυθμιζόμενες τιμές (regulatory holidays), και (iii) την επιβολή πρόσβασης σε ρυθμιζόμενες τιμές για ένα χρονικό διάστημα και έπειτα τη μη επιβολή υποχρεωτικής πρόσβασης (sunset clauses).
- Απόκλιση σε όρους δομής της τιμής πρόσβασης, δηλαδή απόκλιση από την ανά χρήση τιμή πρόσβασης, επιβάλλοντας μία τιμή πρόσβασης που θα αποτελείται από ένα σταθερό και ένα μεταβλητό (ανά χρήση) μέρος.

Η σχετική βιβλιογραφία εξετάζει την αποτελεσματικότητα των παραπάνω αποκλίσεων στα κίνητρα για επενδύσεις σε NGA δίκτυα και στην επίτευξη ενός ανταγωνιστικού περιβάλλοντος προς όφελος των καταναλωτών. Το βασικό συμπέρασμα που εξάγεται από τις αντίστοιχες μελέτες είναι ότι δεν υπάρχει μια ομόφωνη άποψη σχετικά με το ποια ρυθμιστική πολιτική μπορεί να οδηγήσει στην ανάληψη του κοινωνικά βέλτιστου ύψους επενδύσεων (δηλαδή να επιτυγχάνει στατική και δυναμική αποδοτικότητα), καθώς τα αποτελέσματα επηρεάζονται σε μεγάλο βαθμό από το κόστος της επένδυσης και την επίδραση των επενδύσεων στην προθυμία των καταναλωτών να αγοράζουν τις νέες υπερ-ευρυζωνικές υπηρεσίες.

Η παρούσα διδακτορική διατριβή συνεισφέρει στη σχετική βιβλιογραφία που εξετάζει τον αντίκτυπο των δύο πρώτων αποκλίσεων στο στόχο των ρυθμιστικών αρχών να ενθαρρύνουν τις επενδύσεις σε NGA δίκτυα και να προωθήσουν τον ανταγωνισμό προς όφελος της κοινωνίας. Πιο συγκεκριμένα, οι μελέτες που εξετάζουν την επίπτωση από την απόκλιση από τις κοστοστρεφείς τιμές στις επενδύσεις και στην κοινωνική ευημερία θεωρούν ότι η τιμή πρόσβασης σχετίζεται θετικά με το ύψος της επένδυσης. Αυτό πρακτικά σημαίνει ότι όσο μεγαλύτερη η αναβάθμιση του δικτύου πρόσβασης ή/και όσο γεωγραφικά εκτενέστερο είναι το NGA δίκτυο τόσο μεγαλύτερη η αποζημίωσή που λαμβάνει ο επενδυτής μέσω της τιμής πρόσβασης για τον κίνδυνο που αναλαμβάνει. Όταν μια τέτοια τιμή πρόσβασης τίθεται από τις ρυθμιστικές αρχές πριν την ανάληψη των επενδύσεων θεωρούμε ότι η επένδυση γίνεται υπό ρυθμιστική βεβαιότητα. Αυτή η θεώρηση δεν είναι αρκετά ρεαλιστική καθώς οι ρυθμιστικές αρχές δε μπορούν να δεσμευτούν σε μια ρυθμιστική πολιτική για χρονικό διάστημα ίσο με τον κύκλο ζωής των NGA δικτύων. Για αυτόν το λόγο, ένα μεγάλο μέρος της βιβλιογραφίας θεωρεί ότι οι τιμές πρόσβασης που είναι εξαρτώμενες από το ύψος της επένδυσης τίθενται σε ισχύ μετά την ανάπτυξη των NGA δικτύων. Αν και αυτές οι μελέτες θεωρούν ότι η επένδυση γίνεται υπό ρυθμιστική αβεβαιότητα, υποθέτουν ότι ο ρυθμιστής θα θέσει την αναμενόμενη τιμή πρόσβασης που είναι σε συνάρτηση με το ύψος της επένδυσης.

Αντίθετα με αυτές τις μελέτες, η παρούσα διατριβή μοντελοποιεί το γεγονός ότι οι ρυθμιστικές αρχές έχουν σημαντικά κίνητρα να αποκλίνουν από την εξαρτώμενη από την επένδυση τιμή πρόσβασης όταν θα έχει πλέον δημιουργηθεί το NGA δίκτυο και επομένως να θέσουν την τιμή πρόσβασης που μεγιστοποιεί την κοινωνική ευημερία. Πιο συγκεκριμένα, η παρούσα διατριβή υποθέτει ότι οι ρυθμιστικές αρχές θα θέσουν την εξαρτώμενη από την επένδυση τιμή πρόσβασης με μία συγκεκριμένη πιθανότητα ή θα θέσουν την τιμή πρόσβασης ίση με το κόστος παροχής της πρόσβασης με τη συμπληρωματική πιθανότητα. Τα αποτελέσματα έδειξαν ότι όταν το κόστος της επένδυσης είναι σχετικά μικρό σε σχέση με τη θετική επίδραση της επένδυσης στη ζήτηση για τις νέες υπηρεσίες, ο επενδυτής υποεπενδύει σε σχέση με το κοινωνικά επιθυμητό επίπεδο επένδυσης. Αντίθετα, στη πιο ρεαλιστική περίπτωση όπου η θετική επίδραση της επένδυσης στη ζήτηση για τις νέες υπηρεσίες είναι μικρή σε σχέση με το κόστος της επένδυσης, ο επενδυτής μπορεί να υποεπενδύει ή να υπερεπενδύει ανάλογα με την πιθανότητα επιβολής της κοστοστρεφούς τιμολόγησης. Το κύριο συμπέρασμα από την παρούσα μελέτη είναι ότι η επίτευξη του κοινωνικά βέλτιστου επιπέδου επενδύσεων δεν εξαρτάται μόνο από τις επικρατούσες συνθήκες ζήτησης και κόστους, αλλά και από τη ρυθμιστική αβεβαιότητα.

Επιπροσθέτως, η παρούσα διδακτορική διατριβή συνεισφέρει στη βιβλιογραφία που εξετάζει την επίδραση της μη υποχρεωτικής ρύθμισης στις επενδύσεις και στην κοινωνική ευημερία. Όπως είναι αναμενόμενο, η μη υποχρεωτική ρύθμιση μεγιστοποιεί τα κίνητρα για ανάληψη επενδύσεων, αλλά έχει αρνητικές επιπτώσεις στον ανταγωνισμό και κατ' επέκταση στην κοινωνική ευημερία. Η παρούσα διατριβή συγκρίνει τα κίνητρα ενός μονοπωλητή NGA υπηρεσιών να επεκτείνει το NGA δίκτυό του στις λιγότερο πυκνοκατοικημένες περιοχές κάτω από το καθεστώς της ενιαίας και της διακριτής τιμολόγησης των NGA υπηρεσιών λιανικής. Παρατηρείται ότι τα κίνητρα του μονοπωλητή να επεκτείνει την επένδυσή του στις λιγότερο πυκνοκατοικημένες περιοχές είναι μεγαλύτερα υπό το καθεστώς της διακριτής τιμολόγησης, ενώ το συγκεκριμένο καθεστώς οδηγεί και σε μεγαλύτερο επίπεδο κοινωνικής ευημερίας όταν το κόστος της επένδυσης δεν είναι εξαιρετικά μικρό. Επομένως, σε αυτήν την περίπτωση, οι ΕΡΑ θα πρέπει να επιτρέπουν στον μονοπωλητή να θέτει διαφορετικές τιμές λιανικής σε κάθε γεωγραφική περιοχή καθώς αυτή η πολιτική ενθαρρύνει τόσο τις επενδύσεις όσο και την κοινωνική ευημερία. Στην αντίθετη περίπτωση, η ενιαία τιμολόγηση θα πρέπει να επιβληθεί για να αμβλύνει τις αρνητικές συνέπειες της μη ρύθμισης στην κοινωνική ευημερία.

Όλες οι μελέτες που έχουν προαναφερθεί (τόσο οι υπάρχουσες όσο και της παρούσας διατριβής) θεωρούν ότι οι επενδύσεις σε NGA δίκτυα αφορούν είτε την ποιότητα των NGA δικτύων, είτε τη γεωγραφική κάλυψη αυτών. Στην πρώτη περίπτωση, η γεωγραφική κάλυψη είναι εξωγενώς οριζόμενη και επομένως ο επενδυτής αποφασίζει το μέρος του δικτύου πρόσβασης που θα αντικατασταθεί από οπτικά στοιχεία, καθώς και την αρχιτεκτονική υλοποίησης, δηλαδή αποφασίζει την ποιότητα του NGA δικτύου που σχετίζεται με την παρεχόμενη ταχύτητα πρόσβασης στο διαδίκτυο. Στη δεύτερη περίπτωση, η ποιότητα του NGA δικτύου είναι εξωγενώς οριζόμενη και επομένως ο επενδυτής αποφασίζει σε ποιες περιοχές θα εγκαταστήσει τη συγκεκριμένη ποιότητα δικτύου, δηλαδή τη γεωγραφική κάλυψη του NGA δικτύου. Στην πραγματικότητα όμως, η απόφαση για επένδυση σε NGA δίκτυα είναι μια διδιάστατη απόφαση που αφορά τόσο την παρεχόμενη ποιότητα, όσο και τη γεωγραφική κάλυψη. Αυτό συνεπάγεται ότι ο επενδυτής αποφασίζει την ποιότητα των NGA δικτύων που θα αναπτύξει σε κάθε γεωγραφική περιοχή.

Η παρούσα διατριβή μοντελοποιεί το παραπάνω γεγονός για να εξετάσει αν η ανάπτυξη ενός γεωγραφικά διαφοροποιημένου NGA δικτύου οδηγεί στην κοινωνικά βέλτιστη επενδυτική απόφαση. Παρατηρείται ότι ένας μονοπωλητής υποεπενδύει σε σχέση με τη κοινωνικά βέλτιστη παρεχόμενη ποιότητα σε κάθε γεωγραφική περιοχή, ενώ είναι διατεθειμένος να επενδύσει σε όλες τις γεωγραφικές περιοχές, αν και στις λιγότερο πυκνοκατοικημένες το μέρος του χάλκινου δικτύου πρόσβασης που αντικαθίσταται από οπτικές ίνες είναι αμελητέο. Τα συγκεκριμένα αποτελέσματα είναι συγκρίσιμα με τους στόχους της Ψηφιακής Ατζέντας για την Ευρώπη καθώς οι συγκεκριμένοι στόχοι αναφέρονται τόσο στις παρεχόμενες ευρυζωνικές ταχύτητες, όσο και στη γεωγραφική κάλυψη. Η παρούσα μελέτη έδειξε ότι η παροχή ταχυτήτων τουλάχιστον 30Mbps σε όλους τους Ευρωπαίους πολίτες το 2020 είναι ένας εφικτός στόχος όταν η ζήτηση για τις αντίστοιχες υπηρεσίες είναι αρκετά ελαστική, ενώ η παροχή 100Mbps στο 50% των Ευρωπαϊκών νοικοκυριών το 2020 δεν είναι εφικτός στόχος.

Το κύριο συμπέρασμα που προκύπτει από την έως τώρα ανάλυση είναι ότι η μετάβαση από τον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω των χάλκινων δικτύων στον ανταγωνισμό για παροχή διαφοροποιημένων υπηρεσιών μέσω των NGA δικτύων είναι μία πολύπλοκη διαδικασία όπου ο ρόλος των ρυθμιστικών αρχών είναι αναμφίβολα σημαντικός, αλλά η βέλτιστη ρυθμιστική πολιτική βρίσκεται υπό συνεχή συζήτηση και διαμάχη. Άλλωστε ο συγκεκριμένος στόχος των ρυθμιστικών αρχών είναι ένα ενδιάμεσο στάδιο προς την επίτευξη δυναμικής αποτελεσματικότητας όπου κάθε πάροχος θα κατέχει τις δικές του ιδιόκτητες NGA υποδομές και επομένως ο ανταγωνισμός θα στηρίζεται στις υποδομές και όχι στις υπηρεσίες. Αυτός ο τύπος του ανταγωνισμού αναμένεται να οδηγήσει σε έναν αέναο ανταγωνισμό για παροχή καινοτόμων και ποιοτικά διαφοροποιημένων υπηρεσιών μέσω επενδύσεων σε καινοτόμες υποδομές, όπου η ρυθμιστική παρέμβαση δε θα είναι πλέον απαραίτητη. Αυτή η κατάσταση περιγράφει τον μελλοντικό στόχο των ΕΡΑ.

Η σχετική βιβλιογραφία προτείνει την εφαρμογή της λεγόμενης «σκάλας των επενδύσεων» (“ladder of investment”). Η συγκεκριμένη πολιτική βασίζεται στο γεγονός ότι ένας εναλλακτικός πάροχος θα αναπτύξει σταδιακά ένα NGA δίκτυο επενδύοντας στα λιγότερο αναπαραγώγιμα δικτυακά στοιχεία όταν αποκτήσει ένα αρκετά μεγάλο μερίδιο αγοράς. Αυτό σημαίνει ότι σταδιακά θα έχει την ανάγκη να χρησιμοποιεί όλο και λιγότερα δικτυακά στοιχεία του παρόχου/επενδυτή σε NGA δίκτυα. Η ladder of investment θεώρηση προτείνει η τιμή πρόσβασης στα περισσότερο αναπαραγώγιμα στοιχεία να αυξάνεται καθώς ο εναλλακτικός πάροχος αποκτά όλο και μεγαλύτερο μερίδιο αγοράς, έτσι ώστε να έχει τα κατάλληλα κίνητρα να επενδύσει στα λιγότερο αναπαραγώγιμα δικτυακά στοιχεία. Με αυτόν τον τρόπο θα επιτευχθεί η σταδιακή εγκαθίδρυση του ανταγωνισμού για επενδύσεις σε δικτυακές υποδομές. Παρόλο που η συγκεκριμένη πρακτική έχει προταθεί από τη Σύσταση της Ευρωπαϊκής Επιτροπής για την πρόσβαση σε NGA δίκτυα και έχει εφαρμοστεί από αρκετές ΕΡΑ, τόσο θεωρητικές όσο και εμπειρικές μελέτες έχουν ασκήσει δριμεία κριτική στη συγκεκριμένη πρακτική κυρίως για την αποτελεσματικότητά της να εκπληρώσει το σκοπό της. Όμως, τόσο η ladder of investment πρακτική όσο και οι μελέτες που της ασκούν κριτική, εστιάζουν την έρευνά τους μόνο στα κίνητρα των εναλλακτικών παρόχων να επενδύσουν σε ιδιόκτητες NGA υποδομές, θεωρώντας ότι υπάρχει κάποιος πάροχος (κυρίως ο κατεστημένος) ο οποίος έχει ήδη αναπτύξει ένα NGA δίκτυο.

Στην πραγματικότητα όμως οι ρυθμιστικές αποφάσεις που αφορούν την επίτευξη του παρόντος και του μελλοντικού στόχου των ρυθμιστικών αρχών είναι αλληλένδετες καθώς η ρυθμιστική πολιτική που πρόκειται να εφαρμοστεί για να ενισχύσει τα κίνητρα των εναλλακτικών παρόχων να αναπτύξουν ιδιόκτητες δικτυακές υποδομές επηρεάζουν την απόφαση του αρχικού επενδυτή να επενδύσει σε NGA δίκτυα. Αυτό σημαίνει ότι η μετάβαση από τα δίκτυα πρόβασης χαλκού σε αυτά των οπτικών ινών, που αντιπροσωπεύει το σημερινό στόχο των ρυθμιστικών αρχών, γίνεται ακόμα πιο περίπλοκη.

Η παρούσα διδακτορική διατριβή προτείνει μία ολοκληρωμένη προσέγγιση που λαμβάνει υπόψη τη συσχέτιση μεταξύ του παρόντος και του μελλοντικού στόχου των ρυθμιστικών αρχών. Συγκεκριμένα, η προτεινόμενη προσέγγιση στηρίζεται στις βασικές αρχές των Credit Default Swap (CDS) συμβολαίων που χρησιμοποιούνται κατά κόρον στις χρηματοοικονομικές αγορές. Αρχικά, μία ΕΡΑ δεσμεύεται να αποζημιώσει έναν επενδυτή σε NGA δίκτυα για το μέρος της επένδυσης που δε θα έχει ανακτηθεί έπειτα από ένα προκαθορισμένο και αμοιβαία συμφωνημένο χρονικό διάστημα. Η ανάκτηση της επένδυσης είναι άμεσα συνυφασμένη με τη διείσδυση των NGA υπηρεσιών. Ως αντάλλαγμα, ο επενδυτής κάνει περιοδικές καταβολές στην ΕΡΑ ανάλογα με το μη ανακτηθέν μέρος της επένδυσης και την πιθανότητα μη ανάκτησης αυτού. Όμως, η ΕΡΑ επιλέγει να αφαιρέσει το συγκεκριμένο ποσό από τις αναμενόμενες συνολικές πληρωμές που κάνει (σε αυτό το προκαθορισμένο διάστημα) ο εναλλακτικός πάροχος στον επενδυτή για να έχει πρόσβαση στο NGA δίκτυο.

Με βάση αυτές τις αρχές υπολογίζεται μια αρχική τιμή πρόσβασης που θα ισχύει όσο η σωρευτική ανάκτηση της επένδυσης δεν αποκλίνει από την αρχικά εκτιμώμενη σωρευτική ανάκτηση περισσότερο από ένα προκαθορισμένο και αμοιβαία συμφωνημένο ποσοστό. Σε αντίθετη περίπτωση, η ΕΡΑ αναθεωρεί την τιμή πρόσβασης σε συγκεκριμένες χρονικές περιόδους βάσει προκαθορισμένων κανόνων. Αποδεικνύεται ότι όταν η επένδυση σε NGA δίκτυα είναι επιτυχής, η αναθεωρημένη τιμή πρόσβασης που προκύπτει ενδογενώς αυξάνεται και επομένως ο εναλλακτικός πάροχος έχει σημαντικά κίνητρα να ανέβει τη σκάλα των επενδύσεων. Αντίθετα, όταν η επένδυση σε NGA δίκτυα είναι λιγότερο επιτυχής από το αναμενόμενο, η αναθεωρημένη τιμή πρόσβασης που προκύπτει ενδογενώς μειώνεται και επομένως ο εναλλακτικός πάροχος αυξάνει το μερίδιο αγοράς του και τα κέρδη του. Στην πρώτη περίπτωση, ο εναλλακτικός πάροχος καθίσταται περισσότερο αποδοτικός ανταγωνιστής στην παροχή ποιοτικότερων υπηρεσιών, ενώ στη δεύτερη περίπτωση, ο εναλλακτικός πάροχος καθίσταται περισσότερο αποδοτικός ανταγωνιστής στην παροχή (οριζοντίως) διαφοροποιημένων υπηρεσιών. Στην πράξη, το προτεινόμενο εργαλείο προσαρμόζεται έτσι ώστε να υποκινήσει τον κατάλληλο τύπο ανταγωνισμού αναλόγως των συνθηκών. Σε κάθε περίπτωση, το προτεινόμενο εργαλείο αναμένεται να οδηγήσει σε ανάκτηση όλης της επένδυσης στο τέλος του προκαθορισμένου χρονικού διαστήματος.

Αξίζει να σημειωθεί ότι η προτεινόμενη προσέγγιση είναι η μόνη στη σχετική βιβλιογραφία που λαμβάνει υπόψη όλες τις προτεινόμενες αρχές της Σύστασης της Ευρωπαϊκής Επιτροπής για την πρόσβαση σε NGA δίκτυα. Εκτός από τη μεγάλη καινοτομία της παρούσας προσέγγισης, η συγκεκριμένη εργασία έχει και ως στόχο την υποκίνηση μιας εποικοδομητικής συζήτησης σχετικά με την εφαρμογή της προτεινόμενης προσέγγισης από τις ρυθμιστικές αρχές, αλλά και τη χάραξη ενός νέου κλάδου της σχετικής βιβλιογραφίας που θα υπερβαίνει τον κλασικό τρόπο θεωρητικής μοντελοποίησης των ρυθμιστικών παρεμβάσεων.

Από όλα τα παραπάνω καθίσταται σαφές ότι η παρούσα διδακτορική διατριβή μοντελοποιεί τη ρυθμιστική παρέμβαση σε κάθε μετάβαση από ένα σημαντικό στάδιο σε ένα άλλο κατά την εξέλιξη των τηλεπικοινωνιακών δικτύων. Κάθε μία μετάβαση σχετίζεται με έναν μοναδικό στόχο των ρυθμιστικών αρχών που αντιπροσωπεύει μια μετάβαση προς την εγκαθίδρυση ενός ανταγωνιστικού περιβάλλοντος όπου η ρυθμιστική παρέμβαση δε θα κρίνεται αναγκαία. Σε αυτό το μακροπρόθεσμο περιβάλλον, η ταυτόχρονη επίτευξη στατικής και δυναμικής αποδοτικότητας είναι εφικτή. Επομένως, η παρούσα διατριβή όχι μόνο περιγράφει το παρελθόν, το παρόν και το μέλλον των τηλεπικοινωνιακών δικτύων, αλλά και συνεισφέρει στη μοντελοποίηση των ρυθμιστικών παρεμβάσεων που εφαρμόστηκαν ή πρέπει να εφαρμοστούν για να διευκολύνουν τη μετάβαση από την πρώην κρατική μονοπωλιακή αγορά στην επίτευξη του ανταγωνισμού για παροχή ποιοτικά διαφοροποιημένων υπηρεσιών μέσω των επενδύσεων σε ανταγωνιστικές NGA υποδομές.

Πιο συγκεκριμένα, η παρούσα διδακτορική διατριβή ανέδειξε ορισμένα χρήσιμα συμπεράσματα που είχαν παραβλεφθεί από τις υπάρχουσες μελέτες:

- Η κοστοστρεφής τιμολόγηση που εφαρμόστηκε από τις ΕΡΑ κατά την απελευθέρωση της αγοράς των τηλεπικοινωνιών για την προώθηση του service-based competition, ήταν η σωστή επιλογή καθώς οδηγεί τον entrant να πάρει την “make-or-buy” απόφαση που οδηγεί όχι μόνο σε productive efficiency, αλλά και σε allocative efficiency. Αυτό σημαίνει ότι η κοστοστρεφής τιμολόγηση επιτυγχάνει τον βραχυπρόθεσμο στόχο των ρυθμιστικών αρχών να επιτύχουν static efficiency.
- Η βέλτιστη ρυθμιστική πολιτική που θα πρέπει να εφαρμοστεί κατά τη μετάβαση από τα δίκτυα πρόσβασης χαλκού στα NGA δίκτυα, πρέπει να λαμβάνει υπόψη της όχι μόνο τις επικρατούσες συνθήκες σε όρους κόστους και ζήτησης, αλλά και τη ρυθμιστική αβεβαιότητα καθώς αποδείχτηκε ότι επηρεάζει άμεσα την επίτευξη του παρόντος ρυθμιστικού στόχου για προώθηση της ανάπτυξης του κοινωνικά επιθυμητού NGA δικτύου.
- Στις περιπτώσεις όπου ο επενδύτης δεν έχει την υποχρέωση να παρέχει πρόσβαση στο NGA δίκτυό του θα πρέπει να του δίνεται το δικαίωμα να θέτει διαφορετικές τιμές στις νέες υπηρεσίες λιανικής ανάλογα με τη γεωγραφική περιοχή που αυτές παρέχονται.
- Η ανάπτυξη NGA δικτύων είναι μία διδιάστατη επενδυτική απόφαση καθώς αφορά τόσο την επένδυση σε ποιότητα, όσο και την επένδυση σε γεωγραφική κάλυψη. Επομένως, ένας μονοπωλητής έχει σημαντικά κίνητρα να παρέχει διαφοροποιημένες υπηρεσίες σε όρους ποιότητας σε διαφορετικές γεωγραφικές περιοχές.
- Η εύρεση της βέλτιστης ρυθμιστικής πολιτικής γίνεται ακόμα πιο περίπλοκη αν συνυπολογίσουμε το γεγονός ότι η ρυθμιστική πολιτική που πρόκειται να εφαρμοστεί για να ενισχύσει τα κίνητρα των εναλλακτικών παρόχων να αναπτύξουν ιδιόκτητες δικτυακές υποδομές επηρεάζουν άμεσα την απόφαση του αρχικού επενδυτή να επενδύσει σε NGA δίκτυα. Αυτό συνεπάγεται ότι θα πρέπει να αναπτυχθούν πιο εξεζητημένα μοντέλα που θα υπερβαίνουν τον κλασικό τρόπο θεωρητικής μοντελοποίησης των ρυθμιστικών παρεμβάσεων.

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# 1. INTRODUCTION

The telecommunications industry is probably the most rapidly evolving network industry since it has undergone extensive changes in recent decades mainly motivated by the evolution of new technologies and services, the growing importance of telecommunications for national economies and the development of international trade in telecommunications services. The goal of this thesis is to describe the interplay between the continuously evolving scope of telecommunications regulation and technological development which leads to rapidly changing market structures in the telecommunications industry.

Historically, telecommunications networks were deployed using public funds in order to facilitate the distance communication between people. In particular, in many developed countries nationwide copper networks were built since their technology and architecture were optimal for carrying voice traffic on a circuit switched basis. In addition, each national government also owned the monopoly operator which provided end-users with voice services. Therefore, both network operation and service provision were undertaken by the state-owned monopoly firm.

The liberalization of the telecommunications markets in the United States (US) and Britain in the early 1980s and in Europe in the late 1990s was the result of the conventional wisdom that competition serves consumers and social welfare better than the former state monopoly, both from a short-term perspective, where entry and investment decisions are taken as given as well as from a long-term perspective, where these are treated as endogenous [1]. In addition, the almost simultaneous privatization of the former state-owned monopoly operators (the so-called “incumbents”) was a political decision that stems from the proposition that privately-owned providers are more productively efficient than state-owned operators. Therefore, it was expected that liberalization and privatization would lead to a level playing field for the privately-owned alternative providers (the so-called “new-entrants”) which would compete with the former monopolists.

However, the migration from a state monopoly market to a competitive telecommunications industry required the existence of a sector-specific regulator for the restructuring process of the telecommunications sector. Indeed, regulation can be seen as the implementation dimension that facilitates change. In addition, regulatory intervention is best described as a corrective for market failure, having as its ultimate goal a sufficiently and sustainable competitive market that requires no intervention. Market failure is defined not in terms of specific outcomes, but as the failure of the market to generate efficiency in the allocation of resources. There are seven basic causes of market failure, of which monopolistic supply is predominant in the telecommunications services industry [2]. The reason for such market failure lies in the asymmetric nature of the telecommunications markets.

The most significant source of asymmetry is the fact that the incumbent operators have already installed their own networks, whereas new entrants have to build new networks from scratch or to lease the incumbents’ networks. In particular, the provision of an end-to-end telecommunications service (such as a telephone call or an internet communication) almost always requires a combination of a number of separate components, such as call origination, transportation and call termination. Figure 1 graphically describes the connection between the required network elements for the successful provision of an end-to-end telecommunications service.

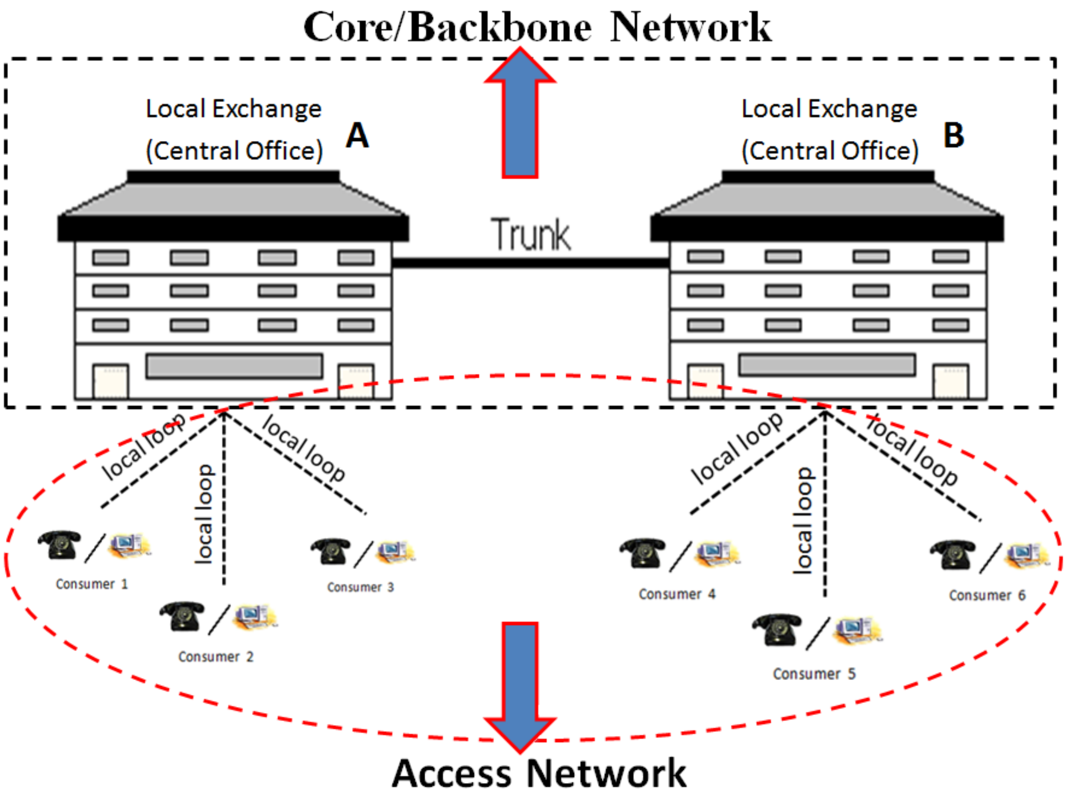


**Figure 1: Core and Access Networks**

In Figure 1, the local loop represents the link that connects each consumer's premises with the nearest central office. In particular, the local loop is defined as the physical twisted metallic pair connecting the network termination point at the subscriber's premises to the main distribution frame (local exchange) or equivalent facility in the fixed public telephone network (central office) [3]. The sum of these connections consists the access network, whereas the sum of the connections between the local exchanges (or central offices) consists the core/backbone network. It is obvious that call origination and termination take place in the access network, whereas transportation takes place in the core/backbone network.

Therefore, a potential entrant needs to build a bypass access network as well as interconnect its central offices. However, it is economically not viable for a new entrant to build a bypass access network due to its natural monopoly characteristics. According to Armstrong [4], an activity is said to be a natural monopoly if it is most cost-effectively carried out by a single firm rather than by several. Local loop presents widespread natural monopoly cost conditions due to the existence of economies of density, which imply that the per unit cost of providing a telecommunications service is decreasing in the population density. In addition, the duplication of the access network requires high fixed connection costs which are related to the cost of digging new ducts and laying new cables. On the contrary, the backbone network does not present natural monopoly characteristics, and hence, a new entrant may invest in its own backbone network. In conclusion, the local loop can be viewed as an extreme natural monopoly for wire-based networks which gives the incumbent the power to exclude competitors from the retail (downstream) market.

In addition, the incumbent typically enjoys several other advantages over any new entrant, such as: (i) the lack or lower quality of added services (e.g. wake-up calls, information services, voice mail) of a new provider; (ii) the lack of reliability of a new entrant's network or reputation associated with this reliability; (iii) the installed consumer base due to switching; and (iv) the lack of consumer information about an entrant's network [5]. This implies that the deployment of alternative access infrastructures, which overcomes the monopoly nature of the local loop, was not economically feasible for new entrants not only because of the huge fixed cost of such deployment, but also due to the low probability of recovering the investment given the non-viable consumer base of the entrants.

As a result, the only solution for new entrants was to purchase monopolized inputs (or essential facilities[1]) from the incumbent. In other words, new entrants required access to the incumbent's access network in order to supply their consumers with their services. However, since the incumbent upstream monopolist was also a supplier of the final services, there was the obvious danger that this integrated firm would seek to exclude competing providers by setting high access prices, thereby raising new entrants' costs [6]. This fact is widely known as "one-way" access problem because the providers of a competitive service need to lease essential facilities from the provider of the non-competitive service but not vice versa. This type of asymmetry results in the failure of the market to generate efficiency in the allocation of resources, and hence, regulatory intervention is needed for correcting such distortion. This implies that market liberalization did not eliminate the need for regulation, but the regulatory focus shifted from the retail to the wholesale market.

Regulation in such asymmetric markets was claimed to stimulate competition in the short-run by allowing the entrants to have access to the metallic local loops of the incumbent operators. This form of regulation is widely known as Local Loop Unbundling (LLU), which implies that the incumbent's essential input is, at the wholesale level, separated from its overall facilities or operations, in order to allow for commercial wholesale supply of this input [7].[2] Therefore, unbundling was expected to facilitate entry as firms were enabled to join the market without having incurred huge fixed and sunk investment costs. However, the introduction of competition into the formerly monopolized telecommunications markets led to a fierce debate about the terms and conditions on which competitors would have unbundled upstream access to the historical operators' local loop facilities [8]. The reason is that regulators should achieve too many goals with only one instrument: the determination of the access charge (i.e. the price that new entrants should pay to the incumbent in order to have access to its local loop facilities). According to [1], the optimal regulatory policy should:

- require as little information and data from market participants as possible;

[1] The Canadian Radio-television and Telecommunications Commission (CRTC) defines an essential facility as a monopoly-supplied facility, function, process or service that competitors require as an input in order to provide telecommunications services and which competitors cannot economically or technically duplicate (http://crtc.gc.ca/eng/archive/1997%5CDT97-8.htm).

[2] In fact, there are three alternative forms of unbundling: bitstream access, shared access and full LLU. With bitstream access, entrants are restricted to resale the incumbent's services. With shared access, the incumbent remains in control of the copper line, whereas with fully unbundled access, the alternative operator obtains full control of the copper line. Hereafter, the term "unbundling" will refer to full LLU in order to point out that the entrants have to deploy a core/backbone network that interconnects most of the local exchanges (central offices).

- keep the costs of regulation to society low and in particular, to avoid an overloaded bureaucracy;
- ensure that regulatory measures are temporary rather than permanent, and ultimately superfluous, whenever possible;
- achieve (static) economic efficiency, with a particular focus on improving consumers' surplus, which is achieved through low prices and high quality;
- achieve dynamic efficiency so that investment incentives give rise to socially optimal investment decisions.

Although all aims have to be kept in mind when implementing specific policies, the level of the access charge directly affects the regulators' two-fold goal to achieve both static and dynamic efficiency. Static efficiency concerns the short-run regulatory goal to reduce the incumbent's market power in order to enable alternative operators (new entrants) to enter the market and compete effectively with the incumbent in the downstream market. Unbundling of the local loop facilitates entry by allowing new entrants to have the right to use the same network as the incumbent. As a result, both incumbent and entrants have significant incentives to invest in innovative, differentiated services. Such service-based competition promotes productive efficiency (i.e. existing assets are utilized efficiently) and allocative efficiency (i.e. existing resources are efficiently allocated to the economy). Therefore, service-based competition ensures an evolution to a self-sustaining pro-competitive market structure in which firms behave in a competitive manner, and hence, consumers enjoy the welfare gains from static efficiency (lower prices, better quality and extended variety of services).

On the other hand, dynamic efficiency concerns the long-run goal of access regulation to induce the firms to undertake the socially optimal (efficient) investment decisions in terms of both timing of investments and the extent of network deployment. According to Bourreau and Doğan [9], facilities-based competition, which requires investments in new competing infrastructures from the incumbents and (especially) entrants, leads to efficient investment decisions and adoption of better technologies. In particular, facilities-based competition is regarded as the only means to achieve sustainable competition since it creates a level playing field between the incumbent and entrants [10–12]. Facilities-based competition achieves the full benefits of competition, and hence, consumers enjoy the full welfare gains from dynamic efficiency (maximum market growth in terms of both volume and value so that markets achieve minimized costs, innovative technologies and advanced services).

Although static and dynamic efficiency are not necessarily mutually exclusive and they may coincide in the long run, a trade-off between static and dynamic efficiency is a common outcome in the short run. Since the promotion of efficient entry is a short-run goal in the transition from state monopoly to private and competitive market structures, access regulation should indisputably aim at fostering service-based competition. The reason is that the incumbent enjoys many advantages over the entrants as well as the deployment of a bypass access network is not economically viable for the latter. This implies that mandatory unbundling is a necessary but not sufficient condition to promote static efficiency since the level of the access price significantly affects the right amount of downstream entry and upstream bypass: if the access price is set too low, inefficient excessive entry may occur; on the contrary, too high access prices not only discourage entrants from joining service-based competition, but also provides the entrants with incentives to build inefficient access facilities in order to bypass the incumbent's network [13].

In parallel with the liberalization phase, the technological developments in the communications and information industry as well as the cost pressure of service-based competition led networks to evolve towards digital transmission and packet switching. In fact, the copper wires, which were interconnecting the central offices and constituting the core/backbone network, were gradually replaced by fibre optic cables, whereas new modem technologies allowed the convergence of the existing twisted copper pair telephone lines into the high-speed (or broadband) communications access capability for various services.[3] In other words, such innovations made available the transmission of high data rates over the existing copper access infrastructures. As a result, both incumbent and entrants upgraded their own backbone infrastructures in order to provide both voice (or in more general terms, narrowband bi-directional real-time transmission) and broadband internet connection to their final consumers over the copper access network of the incumbent.

In the last decade the number of internet users as well as the capacity they demand has increased dramatically, and hence, all providers in the developed world have seen a surge in data traffic conveyed by means of packet switched technology. The increasing transmitted volume of data has currently made the traditional access copper networks incapable of providing end-users with the demanded bandwidth. On the contrary, the transmission capabilities of fibre are theoretically unlimited, whereas it also provides high data rates, low loss and low distortion. For this reason, the deployment of fibre access infrastructures, the so-called Next Generation Access (NGA) networks, has received significant interest among all operators since they are regarded as the only future proof solution capable to handle future demand [14]. It is thus obvious that, today, data transmission rather than voice determines network infrastructures [15]. In addition, investment in NGA networks has also attracted the interest of national governments since higher speed broadband services increase the positive impact of broadband on economic growth, productivity at the firm level, employment growth and consumers' welfare [16–19]. However, investment in NGA networks not only requires a huge initial fixed cost, but also is mainly sunk once the investment has been made. This implies that potential investors are reluctant to invest in NGA networks unless they are reimbursed for the risk they incur when investing in such networks.

Perhaps the most challenging task for academics, governments and policy makers is to design a regulatory policy that encourages investments in NGA networks and promotes sustainable competition. In other words, the current regulatory policy focuses on establishing sustainable service-based competition over NGA networks, thus improving both static and dynamic efficiency. This implies that regulators aim at facilitating the migration from service-based competition over copper access networks to service-based competition over NGA networks.

In such cases, the coexistence of static and dynamic efficiency unambiguously results in better economic and welfare outcomes. However, a growing number of

[3] The Asymmetrical Digital Subscriber Line (ADSL) technology is the most pronounced example of an efficient modification of the copper access network in order to better utilize the limited bandwidth provided by such networks.

empirical studies conclude that facilities-based competition has been the main driver for broadband diffusion although they do not find a negative relationship between service-based competition and broadband diffusion [20–23]. Given that broadband penetration positively affects economic growth [24], [25], it can be inferred that facilities-based competition creates a superior potential for economic growth than does service-based competition. Although these studies focus on the broadband access markets, and hence, they mainly assume facilities-based competition between the traditional telecommunications access networks (which use copper pair cables in the local loop) and the cable TV networks (which use different versions of coaxial cables), their results will be probably applied to the ultra-fast broadband access over NGA networks.

Hence, facilities-based competition over NGA networks maximizes the main economic and welfare indices since the full benefits stemming from a sustainable competition level are achieved. However, given the huge investment cost and the uncertainty of NGA investments, it is expected that firms will invest in a sequential order rather than simultaneously. As a result, the future goal of the regulatory policy should be the provision of sufficient investment incentives that promote facilities-based entry in order to foster facilities-based competition over NGA networks. In other words, regulators should gradually incentivize the entrants to invest in their own access infrastructures once the initial investor has deployed its NGA network.

From the above analysis, it is concluded that there are three distinct phases in the evolution of the telecommunications markets which directly affect the optimal mixture of regulatory policy. These phases are: (i) the migration from a state monopoly market to a competitive telecommunications industry; (ii) the migration from service-based competition over copper access networks to service-based competition over NGA networks; and (iii) the migration from service-based to facilities-based competition over NGA networks. It is obvious that a different regulatory policy is required to be implemented in each migration phase in order to fulfill the desirable investment and competition outcomes of each phase.

In fact, each regulatory policy results in a different balance between static and dynamic efficiency. The aim of this thesis is to discuss the optimal regulatory intervention in each migration phase during the evolution of the telecommunications networks. For this reason, the following three chapters study the respective regulatory access pricing policy that should be implemented in each migration phase in order to achieve the past, the current and the future regulatory goal, respectively. In other words, this thesis studies the regulatory policies that achieve the required balance between static and dynamic efficiency that facilitates each migration.

In addition, this thesis contributes to each of the three distinct literature branches that study the optimal regulatory intervention in each phase of access regulation from the liberalization of the broadband markets to the promotion of facilities-based competition over NGA networks. Figure 2 summarizes the past, the present and the future state of telecommunications markets by discriminating among the efficiency goals of access regulation in each migration phase and allocating the contribution of this thesis to each literature branch.

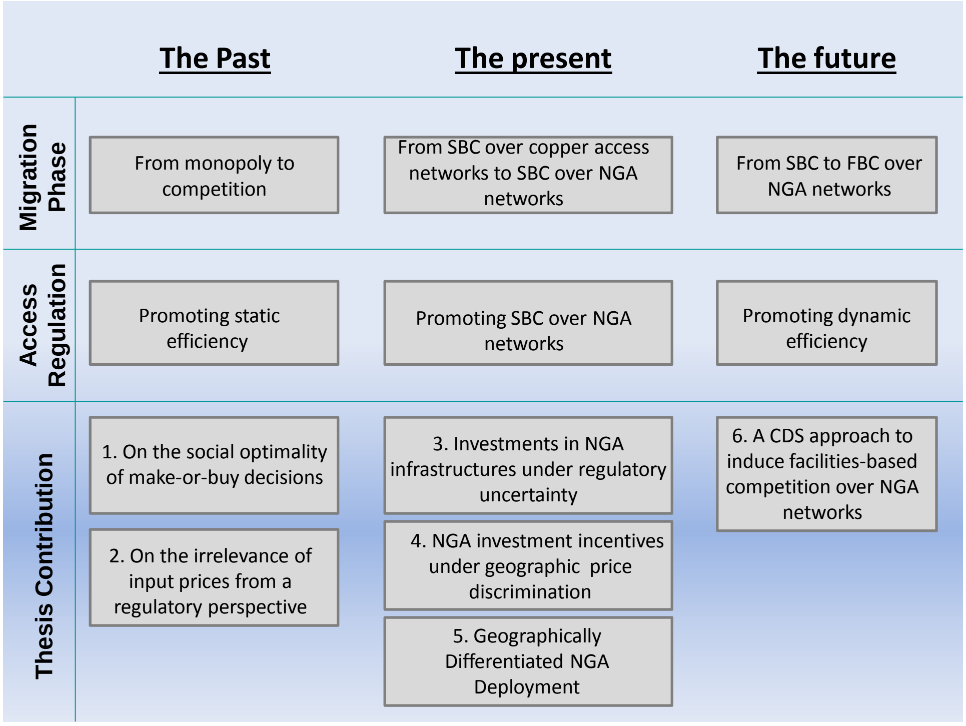


**Figure 2: A graphical representation of the thesis**

In particular, the following two articles, which are part of this thesis, study the impact of access prices on an entrant's incentives to undertake the productively efficient make-or-buy decision which is also socially optimal. In this case, both productive and allocative efficiency is achieved, and hence, efficient entry occurs during the migration from a state monopoly market to a competitive telecommunications industry.

- M. Tselekounis, D. Varoutas, and D. Martakos, "On the social optimality of make-or-buy decisions," *Journal of Regulatory Economics*, vol. 41, no. 2, pp. 238–268, Sep. 2012. [26]
- M. Tselekounis, D. Varoutas, and D. Martakos, "On the irrelevance of input prices from a regulatory perspective," in *5th International conference on competition and regulation (CRESSE), 2-4 July 2010, Chania, Greece*. [27]

Furthermore, the following three articles, which are also part of this thesis, study the impact of different features of the economics of NGA networks on an incumbent's incentives to undertake a larger NGA deployment which also improves social welfare.

- M. Tselekounis and D. Varoutas, "Investments in next generation access infrastructures under regulatory uncertainty," *Telecommunications Policy*, vol. 37, no. 10, pp. 879–892, Nov. 2013. [28]
- M. Tselekounis, D. Maniadakis, and D. Varoutas, "NGA investment incentives under geographic price discrimination," in *40th EARIE Conference, 30 August-1 September 2013, Évora, Portugal*. [29]
- M. Tselekounis, E. Xylogianni, D. Varoutas, and D. Martakos, "Geographically differentiated NGA deployment," accepted in *24th European Regional Conference of the International Telecommunications Society (ITS), 20-23 October 2013, Florence, Italy*. [30]

Last, the following article, which is part of this thesis as well, proposes an innovative approach to induce facilities-based competition over NGA networks.

- M. Tselekounis, D. Varoutas, "A CDS approach to induce facilities-based competition over NGA networks," *submitted to Telecommunications Policy* (under 3rd round revision), 2013. [31]

The above-mentioned research articles are extensively reviewed in the text and are enclosed in Appendix A. The last chapter of this thesis concludes the main policy implications drawn from the discussion about the past, the present and the future state of the telecommunications markets and regulation, summarizes the derived research results of the contributed research articles and proposes directions for future research.

It should be also noted that the research towards the completion of this thesis has led to the publication of some additional articles that are not at the centre of the literature studying the optimal regulatory intervention in each migration phase during the evolution of the telecommunications networks. These research articles are enclosed in Appendix B without being reviewed in the text.

# 2. FROM MONOPOLY TO COMPETITON: PROMOTING STATIC EFFICIENCY

This chapter discusses the role of access prices in the pursuit of regulators to facilitate the migration from a state monopoly market to a competitive telecommunications industry. As it has been already stated in the introduction section, the effectiveness of such migration is closely related to the ability of the access prices to trigger the right amount of downstream entry and upstream bypass. Therefore, in this migration phase, regulators should aim at achieving the short-run goal of local loop unbundling to promote efficient entry. In other words, the optimal access pricing policy should achieve static efficiency by promoting sustainable service-based competition in the retail market.

In particular, this chapter initially presents the access pricing policy that promotes both productive and allocative efficiency when a break-even constraint for the incumbent does not bind (first-best) and when such constraint does bind (second-best). Afterwards, it justifies the choice of European regulators to set the access price at the marginal cost of providing the access and discusses its relationship with the second-best access pricing policy. It should be noted that the main advantage of cost-based access charges is that they give the correct make-or-buy signals to entrants when bypass is a possibility. For this reason, the last part of this chapter studies the impact of the competitive structure of the market on the effectiveness of access prices to induce efficient make-or-buy decisions in terms of both productive and allocative efficiency.

## 2.1 The first-best and the second-best access pricing policies

Consider a simple framework in which there is one vertically integrated incumbent and a non-integrated entrant that requires access to the incumbent's access infrastructures in order to compete with the incumbent in the downstream market. In this case, the regulator has to determine the access price that achieves static efficiency.

The benchmark situation is analytically provided by Armstrong, Doyle and Vickers [6] and Valletti and Estache [32]. It is shown that a benevolent regulator, which aims at maximizing social welfare (i.e. the unweighted sum of consumer surplus and industry profits), has to set all prices (including access) to marginal costs. This implies that the profit margin of the incumbent in both upstream and downstream markets is zero since the access price is set at the marginal cost of providing the access and the retail price at the marginal cost of supplying the final product to consumers. As a result, the socially optimal (first-best) pricing policy achieves allocative efficiency since retail prices are driven towards marginal cost and enhances productive efficiency since the access is priced at cost.

However, it is obvious that such an access pricing policy leaves the incumbent with zero profits. This implies that when the incumbent incurs significant fixed costs in the provision of the access to the entrant, the first-best policy leads the incumbent to have a loss. In fact, the incumbent's access facilities can be used to supply several final services, and hence, an entrant's request for access also incurs joint and common costs to the incumbent. Therefore, the regulators should compensate the incumbents for such fixed costs through the access price. This means that access seekers should contribute to the compensation of the incumbent for the fixed costs related to the access provision. The literature has come up with different answers to this problem, according to the set of objectives pursued by the regulator and to the number of regulatory tools being at the regulator's disposal [33].

Concerning the benchmark situation in this case, it is shown by [6] and [32] that the optimal theoretical access charge that maximizes social welfare subject to a break-even constraint for the incumbent (second-best) is:

*Access price = Marginal Cost of providing the access + Ramsey term*

As a result, when there are fixed costs that should be covered in order to avoid the incumbent from making negative profits, the access price should include an access markup over the related marginal cost. The Ramsey term is inversely proportional to the price elasticity of the demand for the final service, which implies that customers of services that are not price sensitive are required to contribute more to such recovery. It is thus obvious that every consumer contributes to the recovery of fixed costs. Hence, like the benchmark situation in the first-best access pricing policy, the optimal access prices are also derived together with the prices of the final goods.

Nevertheless, it seems fair to say that in practice Ramsey pricing principles are not often heeded for regulated retail tariffs, and access charges are left to correct for the various resulting retail distortions [33]. In addition, the Ramsey charges entail some specific drawbacks that make their practical implementation almost impossible. Initially, there are some political and legal concerns. For example, the incumbent may price discriminate among different downstream firms according to the elasticities of demand of the services they supply. Of course, such discrimination raises antitrust concerns. However, the most significant argument against the use of Ramsey charges is the complexity of the derived access markup formula which requires the knowledge of the different elasticities of demand. For these reasons, policy makers implement simpler ways to determine access charges, such as the cost-based access regulation.

### 2.2 Cost-based access regulation

According to Armstrong [33], the chief benefits of cost-based access charges are two-fold. First, there is no need for information about the demand for the final services. In particular, the only information needed is the cost of providing the access which is needed for all reasonable access pricing policies. Second, cost-based access regulation is the only access pricing policy that gives the correct make-or-buy signals to entrants when bypass is a possibility. A third (less significant) benefit of such prices is that they are fair and non-discriminatory. This means that under cost-based regulation different entrants will not be offered different wholesale terms by the incumbent. In conclusion, cost-based access regulation is appropriate when access charges do not need to perform the additional role of correcting for distortions in the incumbent's retail tariff.

In practice, both in the United States (US) and in the European Union (EU) a light regulation with unregulated retail prices combined with *ex ante* regulation of the upstream access component has become dominant. The Telecommunications Act of 1996 [34] passed by US Congress and administered by the Federal Communications Commission (FCC) as well as the European Commission's (EC) Regulation on Local Loop Unbundling [3] mandated unbundled access to the metallic local loops of incumbent operators at cost-based prices.

However, there are many factors that affect the measurement of the cost of providing the access. The first methodological factor is the cost base employed. In particular, assets may be valued at Historic Costs (HC) or Current Costs (CC). The second methodological factor is the cost standard used. There are several cost standards, such as Marginal Cost (MC), Long Run Incremental Cost (LRIC), Long Run Average Incremental Cost (LRAIC), Total Service Long Run Incremental Cost (TSLRIC), Total Element Long Run Incremental Cost (TELRIC), Fully Distributed/Allocated Cost (FDC) and Stand-Alone Cost (SAC). Last, the methodology or tool used to calculate costs is another source which leads to differences in cost measurement. In fact, the two most widely used cost models are the top-down approach and the bottom-up approach. It is thus obvious that different combinations of cost bases, cost standards and costing approaches result in completely different calculations of the cost of providing the access.[4]

The European Commission indicated the LRAIC as the preferred costing methodology, which is a TSLRIC-type approach. On the other hand, the FCC adopted the TERLIC to implement the Telecommunications Act of 1996. The building block of both cost standards is LRIC, which reflects the incremental costs that arise in the long run with a specific increment in volume of production. Therefore, both LRAIC and TELRIC are forward-looking approaches in the sense that they estimate the costs of rebuilding specific element of network using current technology and best available performance standards. For this reason, it is said that LRIC-type approaches are based on the costs of an efficient firm. In addition, both LRAIC and TELRIC are based on incremental costs, which equal marginal costs for small output changes but may differ substantially from marginal costs if they include large output changes up to entire services. Incremental cost pricing is relevant for entry decisions, whereas marginal cost pricing is relevant for decisions to expand output [35].

Although incremental cost access pricing encourages efficient entry, it does not include any service-specific fixed cost or joint and common/shared costs. Therefore, prices based solely on LRIC are generally considered to be too low and to not sufficiently compensate the incumbent for any additional costs resulted from the entrant terminating and originating its traffic on the incumbent’s network. For this reason, the European Commission adopted the LRAIC costing methodology in which the term “average” implies a policy decision to define the increment as the total service. Hence, LRAIC includes the service-specific fixed costs. On the contrary, the FCC adopted the TELRIC costing methodology which allows the allocation of certain joint and common costs that do not vary with the presence or absence of the element in question. It should be also noted that many European regulators adopted access pricing based on incremental cost with limited markups that account for an allocated part of joint and common costs. The rationale of this policy is similar to that of the second-best access pricing policy: the incumbent should break even. The difference is that although regulators generally set uniform markups to promote competition, the application of Ramsey principles suggests that a non-uniform markup may be more economically efficient [35].

In conclusion, the short-run goal of mandating unbundled access to the local loops of the incumbent at cost-based prices (regardless of the particular methodology employed to calculate such cost) was to promote efficient entry by

[4] An excellent definition of the cost bases, the cost standards and the costing approaches used in telecommunications is provided by [97].

alternative operators. Indeed, cost-based access regulation has led to improved service-based competition in many European countries[5], and hence, they do not need to perform the additional role of correcting for distortions in the incumbent's retail tariff. As a result, it seems that consumers enjoy the welfare gains from static efficiency (i.e. existing assets were used efficiently and prices were driven towards marginal cost).

However, this expectation lacks of theoretical justification since academic research has focused on studying the impact of access prices on an entrant's incentives to undertake the productively efficient make-or-buy decision. The following papers, which are part of this thesis, contribute to the related literature by studying the conditions under which (cost-based) access prices induce the entrant to undertake the efficient make-or-buy decision in terms of both productive and allocative efficiency.

- M. Tselekounis, D. Varoutas, and D. Martakos, "On the social optimality of make-or-buy decisions," *Journal of Regulatory Economics*, vol. 41, no. 2, pp. 238–268, Sep. 2012. [26]
- M. Tselekounis, D. Varoutas, and D. Martakos, "On the irrelevance of input prices from a regulatory perspective," in *5th International conference on competition and regulation (CRESSE), 2-4 July 2010, Chania, Greece*. [27]

These papers are enclosed in Appendix A and reviewed in the next section which surveys the literature that studies the impact of access prices on an entrant's incentives to undertake the efficient make-or-buy decision.

## 2.3 On the social optimality of make-or-buy decisions

Many economists argue that cost-based access prices encourage the right amount of entry, and hence, lead to service-based competition in the downstream market which, in turn, results in lower prices, higher quality and higher social welfare. On the contrary, Sappington [36] shows that input (or access) prices are irrelevant for an entrant's decision to make or buy an input required for downstream production when the competition between the providers in the downstream market is described by the standard Hotelling model. According to Sappington, the reason for this striking result is that previous studies fail to take into account the impact of a new entrant's make-or-buy decision on subsequent retail price competition. When the incumbent sells an upstream input to the new entrant, the incumbent faces an opportunity cost of expanding its retail output. The incorporation of this opportunity cost into the incumbent's total cost makes the incumbent act as if its upstream cost of production were equal to the specified input price. Therefore, regardless of the input price, the entrant will choose to buy (respectively, make) the upstream input whenever the incumbent (respectively, entrant) has an innate upstream cost advantage. Therefore, the entrant's decision always minimizes industry costs and ensures efficient entry and utilization of the telecommunications infrastructure. Thus, the entrant always undertakes the productively efficient make-or-buy decision.

In addition, Tselekounis, Varoutas and Martakos [27] complement the work of Sappington by studying the effectiveness of input prices on inducing the entrant

[5] For example, the market share of the Greek incumbent operator (OTE) has declined from 100% in 2001 to 44.2% in the end of 2011, whereas the wholesale price for full unbundling has declined from 12.6€/month in 2002 to 9.1€/month in the end of 2011. (source: [98], [99])

to undertake the socially optimal make-or-buy decision. They show that input prices do not have an impact on social welfare. The reason is that a marginal increase (decrease) in the input price causes a unit increase (decrease) in the incumbent's profits and a unit decrease (increase) in consumer surplus. As social welfare is the unweighted sum of industry profits and consumer surplus, it is thus not affected by a marginal change in input prices. Therefore, input prices are irrelevant not only for the entrant's productively efficient make-or-buy decision, but also for the regulator's goal to maximize social welfare. In particular, they show that regardless of the established price of the upstream input, the entrant's decision to buy (respectively, make) the upstream input from the incumbent is socially optimal when the incumbent (respectively, entrant) is the least-cost supplier of the input. As a result, in the equilibrium of the Hotelling model, the entrant undertakes the efficient make-or-buy decision in terms of both productive and allocative efficiency regardless of the regulated input price.

However, these results are found to be strongly dependent on the particular model of downstream competition. In particular, Gayle and Weisman [37] consider the impact of input prices on the entrant's incentives to undertake the productively efficient make-or-buy decision under alternative downstream interactions. They show that input prices are not necessarily irrelevant in the Bertrand vertical differentiation model and are not irrelevant in the Cournot model. In addition, cost-based input prices always result in the productively efficient outcome. This implies that any departure from cost-based input prices may distort the efficiency of the entrant's make-or-buy decision.

Tselekounis, Varoutas and Martakos [26] study the robustness of the result concerning the irrelevance of input prices to the entrant's incentives to undertake the productively and allocatively efficient make-or-buy decision when the downstream competition is not characterized by the Hotelling model but downstream interactions are better described by the Cournot or the Bertrand vertical differentiation competition model. They find that the social optimality of the entrant's make-or-buy decision is affected by two crucial factors: (i) the particular level of the price of the upstream input; and (ii) the cost differential between the incumbent's and the entrant's unit costs of producing the upstream input. For this reason, they obtain the range of input prices and upstream cost differential that induce the entrant to undertake the socially desirable decision. They conclude that the entrant's productively efficient make-or-buy decision is socially optimal for the set of input prices that induce the entrant to undertake the efficient decision in the case of Cournot competition and is not necessarily socially optimal in the Bertrand vertical differentiation model.

It is thus obvious that the particular model that describes the competition in the downstream market as well as each provider's efficiency in producing the upstream input have a significant impact on the social optimality of the entrant's (efficient) make-or-buy decision. This implies that regulators should have perfect information about each provider's unit cost of producing the upstream input and the way that the two providers compete in the downstream market in order to draw their optimal access pricing policy. However, when the only goal of regulators is to achieve static efficiency, they should simply set the input prices at the incumbent's marginal cost of producing the upstream input since the results of [26] show that regardless of the type of competition, cost-based access prices lead the entrant to undertake the productively efficient make-or-buy decision which is also socially optimal.[6]

## 2.4 Summary

Chapter 2 presented the access pricing policy that facilitates the migration from a state monopoly market to a competitive telecommunications industry. This implies that such optimal (first-best) access pricing policy encourages the right amount of downstream entry and upstream bypass leading to service-based competition over copper access networks (i.e. achieves static efficiency). In addition, it showed that the first-best policy is not feasible in practice, and hence, it discussed alternative regulatory policies that improve static efficiency. Particular attention was paid to cost-based access prices since they were chosen by many regulators in the US and in the EU. The main reason for such choice was the fact that pricing the access at cost gives the correct make-or-buy signals to entrants.

Indeed, the related literature concludes that although the particular model that describes the competition in the downstream market has a significant impact on the social optimality of the entrant's productively efficient make-or-buy decision, it does not affect the ability of cost-based access prices to induce the entrant to undertake the make-or-buy decision which achieves both productive (i.e. minimization of industry costs) and allocative efficiency (i.e. maximization of social welfare). Therefore, cost-based access prices fulfilled the past regulatory goal of promoting service-based competition over copper access networks.

However, the introduction section made it clear that both technical and economic reasons call for investments in NGA networks. This implies that the current goal of regulatory agencies is to encourage investments in NGA networks without distorting the subsequent competition outcomes. The next chapter discusses the optimal access pricing policy that promotes the current two-fold regulatory goal.

[6] With the exception of an extreme case in the Bertrand vertical differentiation model where the incumbent is much more efficient than the entrant in providing the access.

# 3. FROM COPPER TO FIBRE: PROMOTING SERVICE-BASED COMPETITION OVER NGA NETWORKS

This chapter discusses the role of regulators during the migration from copper access networks to fibre-based access networks. In particular, this chapter discusses the current goal of regulators to provide firms with significant incentives to invest in NGA networks without distorting the subsequent competition level.

After making a short introduction to the main technological aspects of NGA networks, this chapter presents the economics of NGA which conclude that cost-based access prices promote efficient entry and sustainable service-based competition within one network but discourage both incumbents and entrants to invest in new access infrastructures. This fact reflects the standard trade-off between static and dynamic efficiency. For this reason a short analysis concerning the economic rationale for deviating from cost-based regulation with regard to NGA is made.

The most prominent example of such deviation is the regulatory framework proposed by the EC Recommendation on regulated access to NGA [38] which is critically reviewed in this chapter. In addition, this chapter surveys the literature that studies the efficiency and other performance implications of new regulatory approaches that depart from the main principles governing the regulation of the copper access networks (i.e. permanent regulation of the access at usage cost-based prices). This means that such departure may concern the regulatory regime employed (i.e. non-permanent regulation) and/or the characteristics of the access pricing formula (i.e. non-usage-based or non-cost-based access prices).

However, the regulators have significant incentives to deviate from an access policy that encourages private investment incentives by implementing the access policy that promotes competition once the deployment of the NGA network has been made. This thesis models the fact that the regulator might deviate from an access pricing rule that compensates the incumbent for the NGA investment risks through an investment-contingent access price and instead set the access price at the marginal cost of providing the access. Therefore, the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in NGA infrastructures is examined.

Nevertheless, particular attention has received the implementation of the "regulatory holidays" access regime, under which the investor is not imposed to any regulatory constraints for a pre-determined period of time. The reason for such particular attention is the implementation of "access holidays" in the US broadband markets and the dispute between the German government and the European Commission (EC) about the power of national legislation (which envisioned the provision of "access holidays" to the German incumbent operator) to limit the discretionary powers of the national regulator in its exclusive right to assess whether markets should be regulated or not under EU rules [39].

Obviously, such a regulatory policy provides significant investment incentives but also ambiguous outcomes in terms of social welfare. This thesis contributes to the debate about the effectiveness of "regulatory holidays" in providing efficient outcomes by studying: (i) the impact of geographic price discrimination on an unregulated monopolist's incentives to deploy a larger NGA network and on the subsequent social welfare outcomes; and (ii) the optimal decision of an unregulated operator to deploy different quality NGA technologies in geographic areas which differ in their population density.

### 3.1 A short introduction to NGA networks

According to the EC Recommendation [38], NGA networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network.

This general definition implies that fibre optics can replace any part of the copper local loop. However, technical restrictions considerably limit the available NGA architectures. Depending on the part of the copper wire being replaced, there are certain NGA architectures, the most common of which are: (i) Fiber-to-the-Curb (FTTC); and (ii) Fiber-to-the-Home (FTTH).

Regarding the FTTC architecture, the path from the service provider’s central office to the intermediate node (street cabinet) that serves an entire neighborhood exclusively consists of optical fibre. The access of each end-user up to the switch of the street cabinet is realized using the standard copper cables used for the PSTN network and Very High Speed DSL (VDSL) technology over copper cables. Depending on both technology and distance, end-users experience symmetric or asymmetric data rates of up 100Mbps according to the copper length.

The FTTC architecture provides the incumbent with the advantage of connecting its subscribers to existing copper cable infrastructure in the first mile. Additionally, it has lower capital requirements since the NGA investment is done only in part of the access network. However, it has limited time frame since there is a need for capacity doubling every two years.

According to the FTTH architecture, the path from the service provider’s central office to the end user exclusively consists of optical fibre. The fibre is terminated inside the home or the workplace of the end-user. Therefore, each device at the subscriber premises is connected through a dedicated optical fibre to a switch port located at the central office or to the optical splitter which, in turn, is connected to the central office via a single feeder fibre.

Three FTTH technologies are mature enough to use in an NGA investment. The choice of each technology depends on the type of the transmitted service, the infrastructure cost, the existing infrastructure and future plans towards new technologies.

- **Gigabit Passive Optical Network (GPON).** In GPON scenario a first aggregation switch is located in the cabinet between the central office and the user premises. In passive optical networks, each customer is connected to the optical network via a passive optical splitter.
- **Point-to-Point (P2P).** Active Ethernet, also known as Ethernet Switched Optical Network (ESON) or Point to Point (P2P) network provides a dedicated optical fibre from the outdoor active equipment to each end-user.
- **Point-to-Point Ethernet (P2PE).** In P2PE scenario a first aggregation switch is located in the cabinet between the central office and the user premises. The architecture is similar to the one of GPON with the difference that there is active equipment in the cabinet.

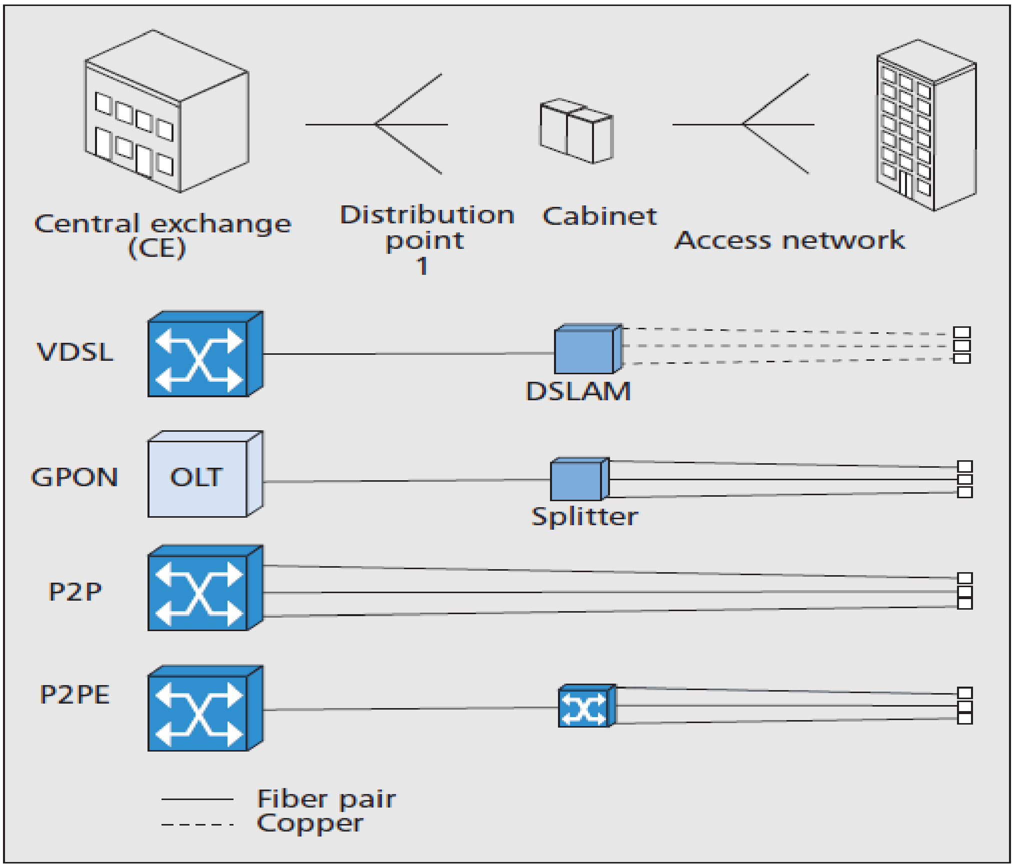


**Figure 3: Different NGA architectures (source:** [40]**)**

### 3.2 The economics of NGA

This section makes a short introduction to some specific economic aspects of NGA investments which should be taken into account during the assessment of the level of access prices that encourage the migration from service-based competition over copper access networks to service-based competition over NGA networks.

#### 3.2.1 The riskiness of NGA investments

Investments in NGA networks not only require a high initial fixed cost, but also are mainly sunk once they have been made. This implies that there are many factors influencing the riskiness of an NGA investment project, the most significant of which are [38], [41], [42]:

- **Demand uncertainty.** This type of uncertainty is related to the uncertainty about future demand for the new fibre-based services. In particular, it includes the uncertainty about: (i) the penetration of the customer base; (ii) the consumers' willingness to pay for the new fibre-based services; (iii) market dynamics and the evolving competitive situation, such as the degree of infrastructure-based and/or cable competition; and (iv) the market shares of the investor and the access seekers.

  It is obvious that the higher the penetration of the potential customer base, the higher the profitability of the investment becomes. Moreover, if the penetration does not reach the critical mass that is required for the creation of the new fibre-based services market, the NGA investment may not even be profitable at all. In addition, intense facilities-based competition due to the existence of competing network platforms, such as cable networks, increases the risk of both penetration and investor's market share. Furthermore, the co-existence of a remaining copper network DSL platform and a new fibre NGA platform increases the risk of the future demand for the new fibre-based services. In particular, the higher the migration period from copper-based services towards NGA-based services, the higher the risk of the penetration of the new NGA-based services. Last but not least, although it is expected that the willingness to pay for the new services will be higher than for the existing ones (since the former offer improved characteristics, such as better quality and higher data rate), it is doubtful that this increase in consumers' willingness to pay will be sufficient for recovering the investment cost.

- **Regulatory uncertainty.** According to [38], regulatory certainty is a key to promoting efficient investments by all operators. Applying a consistent regulatory approach over time is important to give investors confidence for the design of their business plans. Regulatory certainty is provided by fixing the principles of tariff regulation for the whole period of the economic lifecycle of an NGA investment. However, regulatory certainty bears the risk of erroneous intervention stemming from the argument that a regulator's initial assessment may be mistaken. In fact, it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period [42]. Therefore, in providing greater regulatory certainty the regulator has to make another trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare [43]. As a result, regulatory uncertainty is related to the regulator's limited ability to make *ex ante* credible commitments. In order to mitigate the regulatory uncertainty associated with periodical market reviews, National Regulatory Authorities (NRAs) should clarify to the greatest extent possible how foreseeable changes in market circumstances might affect remedies.
- **Systematic risks.** Systematic risk is the variability in outcome caused by macro-economic or economy wide events. This type of uncertainty includes the macro-economic uncertainty relating to the general development of the whole economy and the changes in exchange and interest rates as well as the uncertainty related to technological progress and the costs of deployment.

Considering the significance of the factors affecting the riskiness of an NGA investment project, we would acknowledge the reasons that make potential investors reluctant to invest in NGA networks unless they are reimbursed for the risk they incur when investing in such networks. It is thus expected that cost-based access prices will not provide potential investors with incentives to deploy NGA networks since, under this regime, the investors bear the whole risks of the NGA deployment. The next section reviews the literature that studies the impact of cost-based access prices on promoting investment in network upgrade in order to assess whether such expected negative relationship is scientifically proven.

### 3.2.2 Cost-based regulation of access to NGA networks

A significant part of the literature studying the relationship between access regulation and investment in network upgrade tries to develop theoretical and empirical models in order to assess the impact of cost-based access prices on promoting both static and dynamic efficiency.[7] Although a cost-based access pricing policy is clearly beneficial in the short term, Jorde, Sidak and Teece [44] provides a detailed economic analysis to show that mandatory unbundling at cost-based prices, such as those based on TELRIC methodology, cannot serve as a stepping stone from service-based to facilities-based competition because it distorts the investment decisions of both incumbents and entrants. In particular, the incumbents are adversely affected to upgrade existing facilities or to invest in new ones, whereas the entrants are encouraged to deviate from the socially optimal level of investment and entry. Therefore, when firms invest under regulatory certainty (i.e. the regulator sets the access price prior to the investment decisions), cost-based access prices achieve static efficiency but fail to promote dynamic efficiency.

However, when firms consider that the regulator cannot make *ex ante* credible commitments, which implies that they invest prior to the regulation of the access (i.e. under regulatory uncertainty), they expect that the regulator will set the welfare-maximizing policy (i.e. cost-based access prices) once the NGA network has been in place [45]. In a such non-commitment setting, Foros [46] studies the impact of cost-based access regulation on an incumbent's incentives to invest in network quality in the presence of spillover effects. He shows that cost-based access prices discourage the incumbent to invest in network quality unless it is much more efficient than its rivals in the downstream market. In the latter case, it may use overinvestment as an alternative foreclosure tool. In addition, Kotakorpi [47] points out that, under cost-based regulation, the incumbent underinvests in relation to the socially optimal level.

Although most theoretical studies conclude that unbundling of the local loop at usage (forward-looking) cost-based prices has a negative impact on an incumbent's incentives to invest in new infrastructures, empirical studies provide mixed results. A significant part of these empirical findings use data from the US market in which the access prices are set according to the TELRIC methodology. Ford and Spiwak [48] analyze the 2002 and 2003 local loop rates in order to show that access prices based on TELRIC are associated with increased availability of broadband services and increased availability of competitive broadband services. Thus, such an unbundling policy dampens neither broadband availability nor incumbent's investment incentives. Willig [49] uses US annual data over the 1992-2002 period and finds that that the elasticity of an incumbent's investment with respect to TELRIC prices is such that a 1% reduction in TELRIC prices may be expected to lead to an increase in incumbent's investment of between 2.1% and 2.9%. Hence, these studies support that low access prices incentivize incumbents to invest in network upgrade in order to protect their market shares.

Many other empirical studies argue that mandatory unbundling distorts the incumbents' incentives to invest. Chang, Koski and Majumdar [50] use annual US data from 1994 through 1998 to show that lower access prices provide the US incumbents with disincentives to invest. In addition, Ingraham and Sidak [51] study the daily returns of the three largest US incumbents (BellSouth, SBC Communications, and Verizon) from January 1996 to December 2002. Their empirical findings support that mandatory unbundling at TELRIC prices has decreased the US incumbents' incentives to invest in their own networks. Actual

7 See Cambini and Jiang [100] for an excellent review of the theoretical and empirical literature on the relationship between broadband investment and regulation.

data from five countries (the USA, the UK, New Zealand, Canada and Germany) over the 1993-2003 period show that mandatory unbundling of the local loop leads the incumbents to decrease their capital expenditures [52].

Contrary to previous results, Friederiszick, Grajek, and Röller [53] use a comprehensive panel data set (180 fixed-line operators in 25 European countries observed from December 1997 to December 2006) and find that incumbents' investments in network upgrade are relatively indifferent to the unbundling policy that boosts entry by alternative operators. However, Grajek and Röller [54] using almost the same data set show that when the econometric model accommodates the strategic interaction of entrants' and incumbents' investments as well as an endogenous treatment of regulation, then it results in a significant negative effect on the incumbents' incentives to invest in network upgrade. In a more recent study, Garrone and Zaccagnino [55] carry out an empirical analysis on a sample of incumbents from 27 OECD countries (1993-2008 period) and show that mandatory unbundling that boosts service-based competition reduces the incumbent's incentives to invest unless a certain degree of rivalry has already emerged in the markets.

As Jung, Gayle and Lehman [56] point out, although an incumbent's incentives to invest is positively related to the entrants' market shares and negatively to the absolute number of entrants, this competitive effect becomes weaker in a dynamic framework. Therefore it is uncertain whether competition spurred by mandatory unbundling encourages investments in new infrastructures by the incumbents. However, the impact of such unbundling policy on the entrants' incentives to invest in alternative access infrastructures in order to be facilities-based competitors is unambiguously negative.

Friederiszick, Grajek and Röller [53] also assess the impact of unbundling on the entrant's investments in alternative infrastructures. They find that entry regulation provides entrants with disincentives to invest since they show that entrants would more than double their infrastructure over 5 years if they had no regulated access to the incumbents' local loops. Grajek and Röller [54] use almost the same comprehensive data set to confirm that easier access pushes entrants towards service-based competition even if the econometric model accommodates the strategic interaction of entrants' and incumbents' investments as well as an endogenous treatment of regulation. According to Valletti [8], the reason for such negative relationship between an access policy that promotes efficient entry and the entrant's incentives to invest in alternative access networks is that potential entrants, who can free-ride on the incumbent's network, will wait for the incumbent to invest in access infrastructures and then seek access.

The main conclusion from the above analysis is that an access pricing policy that boosts efficient entry and promotes service-based competition within one network (such as cost-based access prices) not only discourages incumbents and, especially, entrants to invest in new facilities, but also results in a substantial deviation from the socially desirable outcomes in terms of network deployment and timing of investments, implying significant losses in dynamic efficiency [23].

The next section discusses the conditions under which a deviation from regulating the NGA access at usage cost-based prices is socially optimal in the sense that it may mitigate the trade-off between static and dynamic efficiency.

### 3.2.3 The economic rationale for deviating from cost-based regulation

According to the EC [38] "*the EU single market for electronic communications services, and in particular the development of very high-speed broadband services, is key to creating economic growth and achieving the goals of the Europe 2020 strategy. The fundamental role of telecommunications and broadband deployment in terms of EU investment, job creation and overall economic recovery was notably highlighted by the European Council*". In addition, referring to work undertaken by the OECD [57], the EC [58] states that "*the cost savings in just four sectors of economy (transport, health, electricity and education) would justify the construction of a national FTTH network*". It is thus obvious that "*the social benefits from investment in digital infrastructures by far exceed the private incentive for investment*" [59]. The reason is that like many infrastructure investments, NGA networks may create positive spillover effects that are not captured in any individual user's willingness to pay. This implies a clear public policy case for governments to facilitate the roll out of NGA networks by reducing the risk for the investor [60].

Recent empirical studies have tried to quantify the positive impact of investing in broadband infrastructures on the main economic and social indices, with the research focus shifting towards the impact of higher speed services. Considering that broadband penetration may be endogenous to the growth process, Czernich, Falck, Kretschmer and Woessmann [16] estimate the effect of broadband infrastructure investments on economic growth in the panel of OECD countries in 1996–2007. They find that after a country had introduced broadband, GDP per capita was 2.7–3.9% higher on average than before its introduction. In terms of subsequent diffusion, an increase in the broadband penetration rate by 10 percentage points raised annual growth in per capita GDP by 0.9–1.5 percentage points. Furthermore, Katz, Vaterlaus, Zenhäusern and Suter [18] estimate the impact of broadband infrastructure investments on German employment and economic output, following the government's National Broadband Strategy that extends through 2014 and the subsequent ultra-broadband evolution from 2015 to 2020. They find that a total investment of close to 36 billion euros in broadband infrastructures would generate a total of approximately 1 million incremental jobs and an additional value added of 33.4 billion euros, while network externalities would result in an additional 137.5 billion euros. In total, this results in 170.9 billion euros of additional GDP (0.60% GDP growth) in Germany.

The main conclusion of the above analysis is that when there are significant social benefits stemming from NGA investments but the private investment incentives are weak, the regulator should reduce the investment risk in order to encourage the wide deployment of NGA networks. This view is also expressed in the Digital Agenda for Europe [61]: "*without strong public intervention there is a risk of a sub-optimal outcome, with fast broadband networks concentrated in a few high-density zones with significant entry costs and high prices. The spill-over benefits created by such networks for the economy and the society justify public policies guaranteeing universal broadband coverage with increasing speeds*".

Considering the positive impact of NGA investments on the economy and the inappropriateness of cost-based access prices for promoting such investments, the European Commission (EC) issued a Recommendation on regulated access to NGA providing the NRAs with guidelines for tackling the trade-off between fostering competition and promoting investments with regard to NGA networks.

### 3.3 A critical review of the EC Recommendation on regulated access to NGA networks

This section presents the main principles of the EC Recommendation on regulated access to NGA [38] and discusses its effectiveness on achieving its primary goal "*to foster the development of the single market by enhancing legal certainty and promoting investment, competition and innovation in the market for broadband services in particular in the transition to next generation access networks*". According to the Recommendation, where an investor operator with Significant Market Power (SMP) is found within Market 4 (market for wholesale network infrastructure access) and/or Market 5 (wholesale broadband access), an appropriate set of remedies should be applied.

The building block of the Recommendation is the fact that when investments in non-replicable physical access are not specific to the deployment of NGA networks (and do not entail a similar level of systematic risk), the risk profile should not be considered to be different from that of existing copper infrastructure. In this case, the access is also regulated at cost-based prices which imply a reasonable return on capital employed. On the contrary, when investments in non-replicable physical access are specific to the deployment of NGA networks, the investor should be compensated for any additional and quantifiable investment risk incurred by investing in NGA networks. Such compensation takes place by including an access markup, which reflects the additional risk of the NGA investments, in the Weighted Average Cost of Capital (WACC) calculation currently performed for setting the price of access to the unbundled copper loop.

Therefore, the access to NGA networks is regulated at cost-based prices which include a risk premium that compensates the investor for any additional and quantifiable investment risk. According to the Dutch Regulatory Authority (OPTA), the total access price includes four elements [62]:

- The cost of providing the access to the NGA networks.
- The WACC applicable to the existing copper local loop. In the course of time this WACC is expected to fluctuate relatively little.
- The fibre premium which is a premium to the WACC for the copper local loop that takes account of the uncertainty about future demand for fibre-based services and the systematic risks of NGA investments. It is expected that the fibre premium will be higher at the beginning of the investment and will decrease gradually in the course of time as uncertainty over the demand for new fibre services decreases.
- The regulatory risk premium which compensates the investor for the regulatory uncertainty.

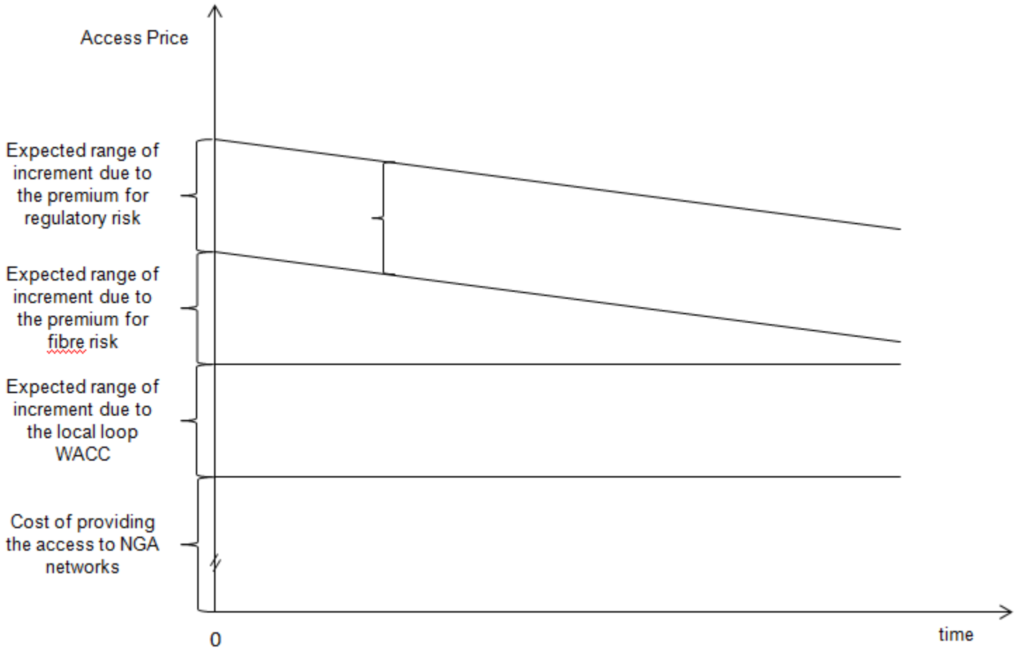


**Figure 4: Cost-based access price including an all-risk premium (based on** [62]**)**

In addition, criteria such as the existence of economies of scale, high retail market shares, control of essential infrastructures and privileged access to equity and debt markets are likely to mitigate the risk of NGA investment for the SMP operator, and hence, should lead to a decrease in the access price. More interestingly, additional mechanisms serving to allocate the investment risk between investors and access seekers and to foster market penetration, such as *ex ante* and *ex post* contracts, could also be used. In such cases, the risk premium is reduced accordingly. The recommended risk-sharing mechanisms are:

- **Volume Discounts.** This scheme is based on the fact that the investment risk decreases with the total number of fibre loops already sold in a given area. Under this scheme, access prices vary in accordance with the volume purchased. Once the access seeker reaches some pre-determined thresholds, it has access to lower access prices. The higher the threshold is, the lower the access price becomes. Hence, volume discounts incentivize access seekers to increase their retail activities and decrease the investment risk incurred by the investor. This, in turn, leads to higher investments and to a more intense competition in the retail market.
- **Long-term contracts.** This scheme is also based on the fact that investment risk decreases with the total number of fibre loops already sold in a given area. Unlike volume discounts, long-term contracts are related to an *ex ante* commitment from the access seeker for using a certain number of fibre loops for a certain period of time. It is reasonable that long-term access contracts would be priced at a lower level per access line than short-term access contracts since the longer the commitment, the lower the investment risk incurred by the investor.

It can be deduced that long-term contracts provide more certainty to the investor than volume discounts because long-term contracts are related to an *ex ante* commitment, whereas volume discounts becomes valid *ex post*. Therefore, the former risk sharing scheme provides more incentives for NGA investments than the latter. Furthermore, long-term contracts incentivize the access seeker to increase its retail activities in order to fulfil its commitment. It can be argued that the access seeker's effort to increase its retail activities is much greater in the case of long-term contracts than volume discounts because in the first case the access seeker strives to reach a certain market share in the retail market (or fulfil its commitment that provides it with a low access price which is lower than volume discounts), whereas in the second case it strives to take a discount without having made any commitment. Therefore, it is expected that long-term contracts rather than volume discounts will lead to more intense competition between the operators that participate in a risk sharing scheme. It should be noted that long-term contracts give the opportunity to alternative operators to compete with the investor not only in the retail market, but also in the wholesale market by reselling the long-term capacity (if not prohibited or restricted by the contractual arrangements or the NRAs).

In conclusion, the EC envisions that a cost-based access price that includes a risk premium for compensating the investor for NGA specific-risk strikes a balance between on the one hand providing adequate incentives for undertakings to invest (implying a sufficiently high rate of return) and promoting allocative efficiency, sustainable competition and maximum consumer benefits on the other (implying a rate of return that is not excessive). It can thus be deduced that the current goal of the regulatory policy in Europe is to promote sustainable service-based competition over NGA networks. Given that the prospective investors in NGA networks (and probably the SMP operators) are for large part the former incumbent operators [42], [43], the regulatory goal is to provide the incumbents with significant incentives to invest in new fibre-based access networks and foster competition in the retail market.

European Telecommunications Network Operators' Association (ETNO), which comprises most of the European incumbents, had already argued that the proposed risk premium will not solve the lack of incentives for widespread NGA roll-out in Europe [63]. The first reason is that a risk premium removes the structural disadvantages of investing only when the NGA investment turns to be successful. Otherwise, the incumbent has to bear all the cost alone since the risk premium does not have any impact on the incumbent's revenues. According to the second reason, even if the probability of success is relatively high, the proposed risk premium does not reflect the structural cost advantage of the second-movers (or, the access seekers) over the investors. Firstly, the second mover can choose between a fixed and a variable cost structure when facing demand uncertainty, heterogeneity, geographical differences and demand evolving over time. This option is widely known as "make-or-buy". Secondly, the access seeker can exit the market at low cost (before making its own investment), whereas the investment of the first mover is typically sunk. Thirdly, the second mover has the option to enter the market once the critical mass has been created. This option is known as "wait-and-see". In addition, even if a risk premium results in higher wholesale revenues for the investor, raising prices for the new infrastructure may lead to a competitive disadvantage of NGA networks vis-à-vis competing platforms and the existing copper network that often will coexist with NGAs for some time.

On the other hand, European Competitive Telecommunications Association (ECTA), with members the majority of the European alternative service providers, argues that alternative operators are in a similar position as the incumbent operators [42]. In particular, ECTA argues that alternative operators invest in all network elements that are replicable and they seek access to network elements that are not replicable. These investments can be also characterized as sunk. Furthermore, the “wait-and-see” option is not costless because if the alternative operator decides to enter the market later, the first mover will have already taken over the most interesting part of the market. Hence, it becomes more difficult or more costly for the alternative network operator to reach the critical market share which is necessary for its viability. Last but not least, the “make-or-buy” option is of low interest in the case of NGA, and especially in the case of FTTH, because the degree of replicability of such networks is very limited. ECTA concludes that the risk premium should only reflect the uncertainty about future demand for new fibre-based services and the regulatory uncertainty. Moreover, the reduction of risk for the investor due to the adoption of risk sharing schemes should be reflected in the risk premium and there should be a sufficient margin between wholesale and retail prices to avoid margin squeeze.

It is thus obvious that there is high ambiguity about the effectiveness of a risk premium on encouraging the incumbents to invest in NGA networks and fostering service-based competition over NGA networks. However, the main innovation of the EC Recommendation is that it deviates from the traditional regulation of the access at cost-based prices by including an access markup into the access pricing formula. The next section reviews the research articles that shift their focus from studying the impact of the principles governing the regulation of the copper access networks on static and dynamic efficiency to the deployment of new regulatory approaches that may promote both static efficiency and investments in NGA networks.

### 3.4 The efficiency implications of alternative regulatory approaches: A literature review

The previous section showed that the current regulatory goal is to encourage the incumbent to invest in new fibre-based access networks and simultaneously promote service-based competition over such networks. The official proposal described by the EC Recommendation states that the access to the incumbent’s NGA network should be provided at cost-oriented prices including a risk premium to reflect any additional and quantifiable investment risk incurred by the investor. Risk allocation mechanisms, such as long-term access pricing and volume discounts, which decrease the risk that an investor incurs when investing in NGA networks, lead to a respective decrease in the risk premium.

This section reviews the literature that provides alternative regulatory practices which aim at achieving the current regulatory two-fold goal. This implies that such regulatory approaches deviate from implementing the principles governing the regulation of the unbundled copper loop to the regulation of the access to NGA networks. In other words, the proposed approaches depart from regulating the NGA access at usage cost-based prices which are designed to stimulate competition in the market by facilitating entry of alternative operators at the cost of dynamic efficiency. Therefore, this departure can take three different forms:

- Deviation from cost-based access prices. This deviation concerns the access pricing policy.
- Deviation from the permanent regulation of access. This deviation concerns the regulatory regime employed.

- Deviation from usage access prices. This deviation concerns the access pricing formula.

The next sections classify the research articles that propose alternative regulatory approaches according the form of deviation from the permanent regulation of NGA access at usage cost-based prices and discuss their performance and efficiency implications.

### 3.4.1 Deviation from cost-based access prices

The EC Recommendation provides a first approach that deviates from the standard cost-based access pricing policy since it proposes the inclusion of an access markup into the access price in order to compensate the incumbent for the NGA investment risk. A second significant deviation discussed in the related literature concerns the regulation of the access to NGA networks at investment-contingent access prices. Such prices are dependent on the level of the investment, and hence, higher NGA deployment results in higher access prices. Therefore, the investor is compensated for the higher uncertainty of an NGA deployment in more rural areas and/or a fibre deployment closer to the consumers' premises.

A first set of papers studies the effectiveness of particular investment-contingent access prices on encouraging the incumbent to undertake the socially optimal investments in NGA networks (i.e. encouraging the incumbent to invest in NGA networks and simultaneously achieving static efficiency) under regulatory certainty.[8] For this reason, these papers assume that the regulator can make *ex ante* credible commitments, and hence, the regulator sets the access price prior to the investment decisions. In this context, Henriques [64] and Sauer [65] show that contrary to a fixed access charge, an access fee that is contingent on firms' (non-overlapping) investments can implement the socially efficient investment level. This outcome holds either if the access charge depends on the investments of both the incumbent and the entrant (former article) or on each operator's own investment level (latter article).

Although this modeling setup is consistent with the EC Recommendation on regulated access to NGA, it is widely known that the regulator has significant incentives to deviate from an investment-contingent access price (once the investments are in place) by setting the access price at the marginal cost of providing the access in order to maximize social welfare. As a result, a second set of papers studies the impact of access regulation on investment incentives and retail competition under regulatory non-commitment. In this case, it is assumed that the regulator cannot make *ex ante* credible commitments, and hence, the firms invest prior to the regulation of the access.

[8] In a static framework (or in a hypothetical world of economic certainty), the incumbent may invest under regulatory certainty if the investment decision is undertaken after the regulation of the access price. However, the regulation of the access is a dynamic process and regulatory remedies are also imposed after the investment decisions. Although theoretical static models are useful for giving an insight into regulatory policies, we should keep in mind that uncertainty can be reduced to risk, possibly even low risk, but not certainty. This fact is also considered in the EC Recommendation since NRAs are encouraged (in order to provide greater certainty) to clarify to the greatest extent possible (i.e. not to fully commit) how foreseeable changes in market circumstances might affect remedies.

Klumpp and Su [66] assume an investment-contingent access price which is revenue-neutral. This implies that each downstream firm contributes to the depreciation of the investment costs according to its market share. They show that, under this rule, the incumbent chooses a higher investment level compared to that of a monopolist and its investment incentives increases with the number of downstream competitors. Thus, they argue that a policy of revenue-neutral open access can increase both static and dynamic efficiency. Sarmento and Brandao [67] compare the investment and competition outcomes of an access price which equals the marginal cost of providing the access plus the average cost of the investments with those derived by the retail-minus regulation and the deregulation of the access price. They conclude that retail-minus regulation leads to better results than cost-based plus regulation in terms of investment level and consumer surplus as long as the regulator carefully defines the retail-minus instrument.

It can thus be concluded that the related literature provides useful results concerning the effectiveness of particular access pricing schemes on promoting both static and dynamic efficiency. However, the articles that examine the relationship between access regulation and investment incentives under regulatory non-commitment take the regulator's decision as given. As a result, they fail to take into account the fact that there is uncertainty about the access pricing policy once the investments are in place. In particular, some articles assume that the firms anticipate that the regulator will set the welfare-maximizing access price [46], [47], whereas others assume that the investment-contingent access price is *ex ante* known [66], [67]. However, in fact, it is uncertain whether the regulator will set an investment-contingent or a welfare-maximizing access price after the NGA deployment.

The following article, which is part of this thesis, models this fact in order to study the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in NGA networks.

- M. Tselekounis and D. Varoutas, "Investments in next generation access infrastructures under regulatory uncertainty," *Telecommunications Policy*, vol. 37, no. 10, pp. 879–892, Nov. 2013. [28]

The motivation, the modeling setup and the main results of this article are presented in the next section.

#### 3.4.1.1 Investments in Next Generation Access infrastructures under regulatory uncertainty

The related literature discusses the effectiveness of two different regulatory approaches on the regulator's goal to achieve the socially efficient investment level when it sets the access price after the investment decision of the incumbent. The first approach supports that the regulator sets a particular investment-contingent access price, which compensates the incumbent for the investment risks, in order to provide significant investment incentives. On the contrary, the second approach argues that the regulator deviates from such *ex ante* known access price (once the investments are in place) by setting the access price at the marginal cost of providing the access in order to maximize social welfare.

Tselekounis and Varoutas [28] modeled the more realistic case in which the regulator sets the access price at the marginal cost of providing the access with some probability and gives an access markup, which equals the average cost of the investments, with the complementary probability. Therefore, it is uncertain which of the two assumptions made in the related literature will prevail when the new access infrastructures are in place.

A non-commitment setting is used in order to take account for regulatory uncertainty. In addition, the retail (downstream) market is characterized as an unregulated duopoly market in which the incumbent (the subsidiary firm of the upstream monopolist) and the entrant (the independent firm) choose quantities simultaneously and independently (i.e. firms compete á la Cournot). The level of NGA investment undertaken by the incumbent leads to an outward parallel shift in the demand, and hence, NGA investments have a positive impact on the demand for the new fibre-based services. Furthermore, the incumbent faces a quadratic NGA investment cost function with respect to the investment level implying that the slope of the marginal investment cost function is linear and increasing in the investment level.

The privately and the socially optimal investment levels are derived as a function of the probability $\alpha \in [0,1]$ of incorporating into the access price an access markup, which equals the average cost of the investments, in order to fully compensate the incumbent for the NGA investment risk. A first significant finding is that a marginal increase in such probability positively affects the private investment incentives and negatively affects the socially optimal investments. The comparison of the privately and the socially optimal investment levels show that there is a unique positive value $\alpha$ denoted by $\tilde{\alpha}$ which induces the incumbent to undertake the socially optimal investments. If $\alpha > \tilde{\alpha}$ (respectively, $\alpha < \tilde{\alpha}$), the NGA investment level chosen by the incumbent is higher (respectively, lower) than the socially optimal one. This implies that any deviation from the socially optimal investments leads to welfare losses.

A second significant result is that the derived value of $\tilde{\alpha}$ is significantly affected by the impact of the investments on demand and the slope of the marginal investment cost function. In particular, the value of $\tilde{\alpha}$ is positively affected by an increase in the impact of investments on demand and negatively affected by an increase in the slope of the marginal investment cost function (ceteris paribus). This implies that, for a given slope, higher consumers' valuation for the NGA services results in higher $\tilde{\alpha}$, which, in turn, leads to higher efficient investment levels. In other words, higher consumer consumers' valuation for the NGA services makes the investments more socially desirable, and hence, the socially optimal investment level is achieved for a higher probability of compensating the incumbent for the investment risks. This result positively affects the incumbent's investment incentives, and hence, the achieved efficient investment level increases as well.

On the contrary, for a given positive impact of the investments on demand, a steeper slope of the marginal investment cost function leads to lower values of $\tilde{\alpha}$. This implies that as the NGA investment becomes marginally more expensive, the society is better off by a lower NGA deployment which is achieved by a higher probability of setting the access price at the marginal cost of providing the access. Therefore, the efficient NGA investment level is achieved for lower values of $\tilde{\alpha}$.

Combining the two aforementioned significant results leads to the main result of Tselekounis and Varoutas [28]:

(i) When the slope of the marginal investment cost function is not particularly steep in relation to the positive impact of investments on demand, the incumbent always underinvests compared to the socially optimal investment level. The reason is that the critical value of the probability of including an access markup into the access price ($\tilde{\alpha}$) is higher that 1. This implies that the socially desirable outcome cannot be achieved even if the regulator commits to an access price scheme that includes an access markup equal to the average cost of the investments. In this case, a higher access markup which leads to $\tilde{\alpha} \leq 1$ seems to be socially desirable.

(ii) On the contrary, in the more realistic case when the impact of investments on demand is low in relation to the slope of the marginal investment cost function, the incumbent may overinvest or underinvest depending on the probability of incorporating an access markup into the access price. In this case $\tilde{\alpha} \in (0,1)$, and hence, the incumbent overinvests for high probability of incorporating an access markup into the access price and underinvests for low probability values. As a result, the optimal social welfare outcome cannot be achieved with the incumbent's profit maximizing investment level when $\alpha \neq \tilde{\alpha}$. This implies that regulatory uncertainty significantly affects the incumbent's incentives to undertake the socially optimal investments in NGA networks.

### 3.4.2 Deviation from the permanent regulation of access

Another significant deviation from the principles governing the regulation of the copper access networks concerns the particular regulatory regime employed. The regulation of the copper access networks is based on the permanent regulation of access in order to promote efficient entry. Although the EC Recommendation proposes the implementation of permanent regulation to the NGA networks, other regulatory regimes have recently attracted the interest of many academics and policy makers due to the lack of investment incentives provided by the permanent regulation of access to the new access infrastructures.

The two extreme regulatory regimes are the "permanent regulation" and the "regulatory forbearance". Permanent regulation implies that the *ex ante* imposed remedies hold for the whole lifecycle of the NGA investment, whereas regulatory forbearance refers to the situation where there is no *ex ante* regulation on NGA networks. It is obvious that regulatory forbearance maximizes investment incentives but also creates significant barriers to entry for access seekers. Therefore, regulatory forbearance will probably fail to promote both static and dynamic efficiency. "Regulatory holidays" and "sunset clauses" are intermediate regulatory regimes between regulatory forbearance and permanent regulation. Under regulatory holidays, the investor is not imposed to any regulatory constraints for a pre-determined period of time, whereas by imposing a sunset clause, the regulator commits that access obligations will be withdrawn after a pre-determined date.

Charalampopoulos, Katsianis and Varoutas [68] as well as Gavosto, Ponte and Scaglioni [69] use a real option approach to study the impact of the four different regulatory regimes (permanent regulation, regulatory forbearance, regulatory holidays and sunset clauses) on the timing of the investment decision of an incumbent to expand to a new network infrastructure. The former article shows that regulatory holidays induce the incumbent to expand its current network as soon as the regulatory holiday season ends, which is long before the expiration date of the option to expand. However, concerning the incumbent's discounted profits, regulatory forbearance and sunset clauses give identical results, followed by regulatory holidays and permanent regulation. The latter article concludes that investment is carried out immediately under forbearance and regulatory holiday regimes, while it is delayed by around two years in the other cases. Therefore, it can be deduced that both articles argue that regulatory holiday regime appears superior to the other regulatory regimes, although the two papers provide different results about the impact of regulatory holidays on the particular timing of the investment.

Of course, the efficiency outcomes are significantly affected by the level of the access prices set under each particular regulatory regime. Nitsche and Wiethaus [70] study the efficiency implications of a combined deviation from the permanent regulation of access at cost-based prices in terms of both the access pricing policy and the regulatory regime employed. In particular, they allow an access pricing scheme that spreads investment costs over total output quantities (i.e. another form of investment-contingent access pricing) for taking into account: (i) different regulatory regimes; (ii) the fact that the success of NGA investments is uncertain; and (iii) regulatory certainty. They show that a regime with Fully Distributed Costs (FDC)[9] or regulatory holidays induce the incumbent to undertake a larger NGA deployment, followed by risk-sharing and Long-Run Incremental Costs (LRIC). In addition, in combining strong competitive intensity with reasonable investment incentives, simulations indicate that a risk sharing approach induces highest consumer surplus, followed by regimes with FDC, regulatory holidays and LRIC. Therefore, they conclude that risk-sharing can be an effective tool since it combines relatively high *ex-ante* investment incentives with strong *ex-post* competitive intensity. They also find that forward-looking cost-based regulation neither induces investments nor consumer surplus, which implies a clear policy for deviating from permanent cost-based access prices.

In combining these results with those of [68] and [69], it can be deduced that although regulatory holidays appear superior to the other regulatory regimes in terms of both NGA investment level and the timing of the investments, their effectiveness on promoting service-based competition is rather ambiguous. For this reason, the next two articles, which are part of this thesis, study the effectiveness of regulatory holidays (or regulatory forbearance in a static framework) to result in improved social welfare outcomes when: (i) the monopolist is allowed to geographically price discriminate; and (ii) the monopolist chooses a mix of NGA networks deployed in different geographic areas.

- M. Tselekounis, D. Maniadakis, and D. Varoutas, "NGA investment incentives under geographic price discrimination," in *40th EARIE Conference, 30 August-1 September 2013, Évora, Portugal*. [29]
- M. Tselekounis, E. Xylogianni, D. Varoutas, and D. Martakos, "Geographically differentiated NGA deployment," accepted in *24th European Regional Conference of the International Telecommunications Society (ITS), 20-23 October 2013, Florence, Italy*. [30]

[9] Under the fully distributed costs regulation, the incumbent may recoup NGA investment costs through the access price, regardless of the NGA's market success since the entrant is forced to cover part of the investment cost.

#### 3.4.2.1 NGA investment incentives under geographic price discrimination

The research articles that study the effectiveness of alternative regulatory approaches on encouraging investments in NGA networks and fostering competition explicitly assume that all consumers equally benefited by a certain extent of NGA deployment. However, it is expected that there will be a significant variation among consumers' willingness to pay for the additional benefits of NGA-based services since there are consumers who place a low valuation to the enhanced characteristics of such services and consumers who have higher valuation for advanced bandwidth-hungry services. The prospective investor in NGA networks could exploit this information by pricing the final services such that they more closely reflect retail consumers' willingness to pay ("value-based" pricing) and/or geographical differences in network costs.

Contrary to uniform pricing, price discrimination is defined as selling the same product to different customers at different prices even if the cost of sale is the same to each other [71]. Price discrimination has recently attracted much interest since regulatory forbearance and holidays could lead to geographic de-averaging of prices that would reflect the geographic variances in market conditions, which may significantly differ from traditional PSTN/DSL conditions. Indeed, after a period of obligation of non-discrimination [72], currently, price discrimination is allowed to a certain (at least wholesale) extent related to NGA networks in Europe in order to foster innovation and welfare growth by promoting investments [38]. Thus, there may be a case for designing remedies that can vary across geographic markets that would be defined as locations with homogeneity in terms of willingness to pay, competitive conditions, cost, etc.

Alexandrov and Deb [73] as well as Valletti [74] study the impact of price discrimination on a monopolist's incentives to invest in quality. This implies that both articles assume that the number of the markets that the quality-enhanced product will be sold is exogenously defined (e.g. the whole country), whereas the investment in quality (i.e. the particular extent of fibre deployment in the local loop) is endogenously derived. In other words, consumers who live in different geographic areas place the same valuation on each particular quality level. It is found that price discrimination results in more investment in quality than uniform pricing, whereas its impact on social welfare depends on the specific underlying industry characteristics.

However, in the NGA context, the main source of variation among consumers' willingness to pay for the additional benefits of NGA-based services is the fact that consumers live in different geographic areas in terms of population density. Indeed, the main take-away of the relevant studies [75], [76] is that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) densely populated areas. As a result, population density has a significant positive impact on the consumers' valuation for ultra high-speed services provided by NGA networks. Therefore, the difference in consumers' willingness to pay for very high-speed services is mainly due to their geographic differentiation rather than on the difference in their valuation for a particular improved quality service.

Contrary to [73] and [74], Tselekounis, Maniadakis and Varoutas [29] compare the impact of retail price discrimination and uniform pricing on a monopolist's incentives to extend its Next Generation Access (NGA) network deployment to less densely populated geographic areas. This implies that the quality of an NGA-based service is exogenously defined (e.g. FTTH), whereas the number of geographic areas (markets) that this service will be provided is endogenously chosen. In other words, consumers who live in different geographic areas place a different valuation on each particular quality level.

It is found that geographic price discrimination provides the monopolist with higher incentives to deploy a larger NGA network (i.e. the NGA investment is extended to rural, less densely populated areas). In addition, geographic price discrimination results in better welfare outcomes than uniform pricing as long as the investment cost is not extremely low. In such cases, the regulator should allow the monopolist to geographically price discriminate since the monopolist chooses the socially optimal pricing regime. On the contrary, when the investment cost is extremely low, uniform pricing is the socially optimal pricing regime, whereas differential pricing maximizes private investment incentives. In such cases, a benevolent regulator may impose the uniform pricing regime in order to mitigate the detrimental impact of regulatory forbearance or holidays on social welfare.

#### 3.4.2.2 Geographically differentiated NGA deployment

The previous section showed that, in a static context, the deployment of NGA networks is a two-dimensional issue. First, the incumbent has to decide the quality of the NGA investment related to the part of the copper access network that will be replaced by fibre optics. Second, the incumbent has to decide the extent of the NGA deployment which concerns the number of geographic areas in which an NGA network will be deployed.[10]

Hitherto, the reviewed literature does not discriminate between the two different dimensions of the NGA investments, and hence, it assumes that a higher NGA investment level indiscriminately reflects either a larger NGA deployment to rural, less densely populated areas or a fibre deployment closer to the consumers' premises. In particular, existing studies assume that a prospective investor in NGA networks chooses either the quality or the geographic coverage of the NGA network. This implies that the investor decides : (i) the quality of the NGA network that will be provided in an exogenously given number of geographic areas; or (ii) the number of geographic areas in which an exogenously given NGA technology network will be deployed. In each case, the investor focuses on one of the two dimensions of the NGA investment decision taking the other dimension as given.

However, in fact, the investor in NGA networks does not choose either the extent of the deployment towards consumers' premises in given geographic areas or the geographic deployment of a particular NGA quality, but it simultaneously decides the NGA quality that will be provided in each geographic area. This implies that a mix of NGA technologies will co-exist according to the underlying demand and cost conditions in each geographic area.

Tselekounis, Xylogianni, Varoutas and Martakos [30] model the demand and cost structures in each geographic area in order to assess the optimal mix of NGA technologies deployed in different geographic areas by a monopolist. In other words, they find the optimal degree of copper replacement by fibre (i.e. the optimal NGA quality) in every geographic area. Based on this relationship, the incumbent chooses the extent of NGA deployment that is the optimal number of geographic areas in which a different quality of NGA network will be provided.

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[10] In a dynamic context, the incumbent has also to decide the timing of the NGA deployment.

In order to derive the optimal mix of NGA technologies deployed in different geographic areas by a monopolist, the authors use the following functions for representing the demand and investment cost, respectively, in each geographic area $i$:

$$p_i = A + \frac{y_i}{x_i^2} - q_i \quad \text{and} \quad C(i) = (x_i y_i^2)/2$$

where $p_i$ and $q_i$ is the retail price and the quantity supplied by the monopolist in each geographic market, $A$ represents the maximum valuation that the consumers place to the basic high-speed broadband service, $x_i$ reflects the geographic NGA deployment and $y_i$ reflects the NGA quality (technology). A larger $x_i$ implies a larger NGA deployment to less densely populated areas, whereas a larger $y_i$ implies a fibre deployment closer to the consumers' premises. It is obvious that, contrary to existing studies which assume an exogenously given slope of the marginal investment cost function, a higher NGA technology positively affects the consumers' willingness to pay, but its impact declines as it is provided to less densely populated rural areas. In addition, contrary to existing studies which assume that a higher level of NGA investment in terms of either technology or coverage leads to a more outward parallel shift in the demand curve (and thus equally benefits all consumers), the investment cost of providing a particular NGA technology becomes marginally more expensive as it is extended to less densely populated areas.

Tselekounis, Xylogianni, Varoutas and Martakos find that both the privately and the socially optimal investment decisions result in a geographically differentiated NGA deployment implying that different quality NGA networks are deployed in different geographic areas. In addition, although a geographically differentiated NGA investment provides the unregulated monopolist with incentives to install a nationwide NGA deployment, the monopolist underinvests compared to the socially optimal levels of both quality and geographic coverage.

Moreover, the authors make several, but plausible, assumptions in order to make their results comparable to the Europe 2020 Strategy [61] which envisions that, by 2020: (i) all Europeans will have access to much higher internet speeds of above 30 Mbps; and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps. They show that the first objective is feasible when the demand for NGA-based services is significantly elastic, whereas the second objective is not a feasible goal.

### 3.4.3 Deviation from usage access prices

The last deviation from the principles governing the regulation of the copper access networks concerns the access pricing formula. In particular, the access pricing formula can be used to allocate the investment risk between the incumbent and the access seekers. Although such risk-sharing mechanisms are not present in the EC Recommendation, OPTA has included them in its proposed measures to reduce the investment risk [43].

Access prices (as well as retail prices) can consist of one-off fees and periodic fees (e.g. monthly rentals). By giving the investor the choice to recoup fixed costs via a one-off fee, the investor can affect his own investment risk and the entry risk resting on the buyers of unbundled fibre access. The advantage of recoupment via a one-off fee is that the investor recoups some of its investment in the early phase of the economic life of the network. This early recoupment of parts of the investment leads to a lower capital requirement over time, a decrease in the investment risk and an increase in the investor's willingness to invest.

The general rule says that the higher the allocation of investments costs to the one-off component, the more investment risk on a per line basis is allocated from the investor to the access seeker. However, charging this one-off fee should not create a barrier to entry for buyers of unbundled fibre access. If relatively many costs are charged as one-off tariffs, this raises the barrier for purchasing services, because a buyer is confronted with higher start-up costs.

Gans and King [77] state that in a dynamic context, the regulator should set a two-part tariff in which the fixed fee is set equal to the economic profit of the access seekers and the usage access fee follows the Ramsey rule. Otherwise, regulatory holidays is a desirable regime that results in the incumbent's earlier investments only when the regulator cannot make *ex ante* credible commitments. The main take-away from the paper of Gans and King is that the regulatory commitment problem has a significant impact on the optimal regulatory policy and that two-part tariffs may be an effective tool in order to promote both static and dynamic efficiency. In addition, Brito, Pereira and Vareda [78] study the impact of the regulatory commitment problem on the effectiveness of two-part access tariffs to solve the dynamic consistency problem of the regulation. They find that when the investment cost is low compared to the investment benefits, two-part tariffs solve the dynamic consistency problem either under regulatory certainty or uncertainty. In this case, the optimal regulatory policy is to set the fixed access price in order to induce investments by the incumbent and the usage access price at the marginal cost of providing the access in order to promote static efficiency. If, on the contrary, the investment cost takes intermediate values compared to the investment benefits, the commitment and the no-commitment games have different equilibria, with the incumbent investing in the commitment equilibrium, and not investing in no-commitment game. Last, if the investment cost is high compared to the investment benefits, investment is not socially desirable under both commitment and no-commitment games. Therefore, contrary to Gans and King, two-part access tariffs may not solve the dynamic consistency problem even when the regulator can commit *ex ante* to a particular access pricing policy.

### 3.5 Summary

Chapter 3 discussed the effectiveness of different access pricing schemes on promoting the current regulatory goal of encouraging investments in NGA networks and fostering service-based competition over such networks. It was shown that cost-based access prices are limited to promote service-based competition within one network since they disincentivize incumbents and, especially, entrants to invest in new access infrastructures. Combining this fact with the huge investment cost of deploying an NGA network and the uncertainty of such investments provides the reasons that explain the reluctance of firms to undertake NGA investments. However, investments in digital infrastructures by far exceed the private incentives for investments. It is thus deduced that there is a clear policy towards a deviation from the permanent regulation of access at cost-based prices in order to compensate the investors for the risk they incur when deploy an NGA network.

The first official deviation from cost-based access prices was proposed by the EC Recommendation of regulated access to NGA which recommends calculating the access at a cost-based form including a risk premium. However, the effectiveness of such pricing policy on promoting service-based competition over NGA networks has been fiercely criticized by both incumbents and entrants. In addition, it was found that regulatory uncertainty has a significant impact on an investor's incentives to undertake the socially optimal NGA investments. Due to these facts, the regulatory holidays regime has recently received much interest. Given that the NGA investments are significantly costly, it was shown that regulatory holidays may increase both investment incentives and allocative efficiency when the monopolist is allowed to geographically price discriminate. However, even under the price discrimination regime, the monopolist underinvests compared to the socially optimal geographically differentiated NGA deployment.

# 4. FROM SERVICE-BASED TO FACILITIES BASED COMPETITION OVER NGA NETWORKS: PROMOTING DYNAMIC EFFICIENCY

Although service-based competition over NGA networks increases both static and dynamic efficiency, the full benefits of competition are only achieved by facilities-based competition. This explains why the ultimate goal of regulators is to promote dynamic efficiency which results in maximum welfare gains, maximum market growth and minimum production costs.

This chapter discusses the future regulatory goal of achieving dynamic efficiency by promoting facilities-based competition over NGA networks. In particular, given that an initial investor has already deployed an NGA network and sustainable service-based competition has been established, the optimal access pricing policy should incentivize the access seekers to gradually invest in their own NGA infrastructures.

The first part of this chapter reviews the proposed regulatory approaches which aim to encourage access seekers to invest in their own fibre-based access networks. Afterwards, a comparison of these regulatory approaches with the current regulatory framework in the European NGA market described by the EC Recommendation is made. It is found that the proposed regulatory approaches not only fail to reflect the basic principles of the EC Recommendation, but also fail to take into account the fact that the regulatory policy implemented in this phase has a direct impact on the initial investor's incentives to invest in NGA networks.

For this reason, the second part of this chapter presents an innovative theoretical approach that not only reflects the current regulatory framework in the European NGA market, but also encourages the initial investor (which is assumed to be the incumbent) to invest in NGA networks, although at the same time it incentivizes the entrants to gradually invest in their own NGA infrastructures. It is shown that the proposed approach, which is based on the basic principles governing a Credit Default Swap (CDS), provides an effective migration path towards facilities-based competition over NGA networks.

## 4.1 Encouraging facilities-based competition: A literature review

This section discusses the impact of access regulation on an entrant's incentives to invest in new access infrastructures in order to act as a facilities-based competitor. In particular, this literature studies whether service-based competition serves as a stepping stone to facilities-based competition or the presence of the option to "buy" the incumbent's facilities represents an opportunity cost when the entrant chooses to engage in infrastructure competition (i.e. creates the so-called "replacement effect").

Cave and Vogelsang [79] point out that the entrants typically invest in replicable assets first and then progress to less replicable ones. Thus, they rank the incumbent's network assets according to their degree of replicability from an entrant's perspective and propose an innovative access scheme in which the price for the less replicable network elements is low but increasing over time as assets are replicated. Therefore, as the entrant's customer bases grow, the access price increases in order to encourage the entrant to invest in the next less replicable asset. This process continues until the entrant invests in its own infrastructure which represents the higher rung in the investment ladder. Thus, the so-called "ladder of investment" theory argues that service-based competition serves as a stepping stone to facilities-based competition. Cave [12] proposes and illustrates methods for assessing the replicability of different assets and sets out the steps which regulators can follow in implementing the approach.

An alternative regulatory tool that resembles the “ladder of investment” approach is the so-called “sunset clause” regulatory regime. By imposing a sunset clause, the regulator commits that access obligations will be withdrawn after a pre-determined date. The building block of both approaches is the expectation that as service-based competition becomes less attractive over time, the entrant will gradually invest in its own network infrastructure. Although sunset clauses and the “ladder of investment” theory have been embraced by many telecommunications regulators and organizations [38], [80–83], the related literature provides mixed results about the effectiveness of each approach to make service-based and facilities-based competition complements in promoting both investments and competition.

Bourreau and Doğan [84] use a dynamic model of technology adoption to compare the impact of unbundling on the entrant’s incentives to compete service-based or facilities-based. Assuming a utility model that captures variety and quality differentiation, they show that an unregulated incumbent sets too low a constant usage rental price for its loops over time, and hence, the entrant adopts the new technology too late from a social welfare perspective. The rationale of such behavior is that a low access price increases the entrant’s profits which represent an opportunity cost when the entrant chooses to engage in infrastructure competition. Therefore, the incumbent avoids a fiercer competition in the retail market by providing the entrant with disincentives to invest in its own infrastructure. The regulatory implication is twofold. First, the regulator who is concerned with promoting facility-based competition should regulate the rental price of the loops; and second, a sunset clause neither incentivizes the entrant to invest in network upgrade nor improves social welfare. Bourreau and Doğan [85] also discuss the impact of unbundling on an entrant’s investment incentives from a dynamic perspective but allows for a time variant rental price as well as a general competitive setting. They show that the optimal regulatory policy is to set the access price at the level that maximizes social welfare under service-based competition until the date at which facilities-based entry is socially optimal, and then to ban access to the incumbent’s infrastructure (or to set too high a price for it) from that date on.

In addition, Avenali, Matteucci and Reverberi [86] assume that developing an alternative infrastructure requires both time and an installed base of consumers which implies that a period of service-based competition is a prerequisite for facilities-based competition in the next period. They find that a multi-period schedule where regulated access charges rise over time is critical to foster efficient infrastructure investment, whereas a sunset clause on regulation dilutes investment incentives. Contrary to [84] and [85], which assume regulatory certainty, they point out that the regulatory commitment problem may affect the robustness of their main result. Thus, they propose that the access price should depend both on time and entry period in order to ensure that late entrants are provided with the same dynamic access conditions. In a more recent paper, Bourreau and Drouard [87] use a general model of competition in order to study the impact of both a “replacement effect” and a “stepping stone effect” on an entrant’s investment to invest in network upgrade. Thus, they allow an initial serviced-based period for the entrant to build its market share progressively. This implies that the entrant might have significant incentives to prolong the service-based competition phase in order to build a larger market share. They show that if facilities-based entry is a short-term (long-term) possibility, the replacement effect (the stepping stone effect) prevails, and hence, a phase of service-based competition delays (accelerates) facilities-based entry.

Therefore, as Bourreau, Doğan and Manant [88] point out, a phase of service-based competition may be a necessary, but not a sufficient, condition to ensure that it will serve as a stepping stone to facilities-based entry if the replacement effect is neutralized. The authors also challenge another assumption of the ladder of investment theory which states that the regulator has the instrument to neutralize the replacement effect. They argue that although access prices that increase over time may neutralize the replacement effect, credibility of regulatory commitments and informational requirements raise several concerns about the successful implementation of this theory.

In addition, the effectiveness of the “ladder of investment” theory to serve as a stepping stone from service-based to facilities-based competition has been criticized not only theoretically but also empirically. Hausman and Sidak [52] use real data from five countries (the USA, the UK, New Zealand, Canada and Germany) over the 1993-2003 period in order to test whether the new entrants use the unbundled loops to evolve into facilities-based competitors. They conclude that although the “ladder of investment” theory is theoretically plausible under certain assumptions yet has not been satisfied in practice. Hazlett and Bazelon [89] use semi-annual US state-level data from December 1999 to December 2004 to examine whether the number of the unbundled lines in one period is correlated with the number of facilities-based line in future periods. Their main conclusion is that the “ladder of investment” theory is rejected since there is no statistically significant relationship between the unbundled lines in one period and the number of facilities-based line in future periods in each US state.

Distaso, Lupi and Manenti [90] use semi-annual data from 12 European countries (study period: January 2005-July 2007) and test the “ladder of investment” theory by looking at the link between the prices of wholesale access services and the relative growth rates of the three alternative inputs that can be used by new entrants to provide access and broadband services to end users: bitstream services, LLU services and their own network. Although they point out that the policies adopted by NRAs are broadly consistent with the “ladder of investment” theory, their graphical results reveal that only few countries (France and Spain) have succeeded in encouraging the entrants to climb the investment ladder due to increasing access prices over time. In a more recent empirical study, Bacache, Bourreau and Gaudin [91] use data covering incumbent and entrant fixed-broadband operators in 15 European member states for 15 semesters (2002-2009) in order to test the “ladder of investment” hypothesis. They find no statistically significant effect of the number of unbundled lines on the number of new access infrastructure lines built by entrants, which implies that there is no evidence in support of the “ladder of investment” hypothesis.

As a result, although the EC Recommendation states that the appropriate array of remedies imposed by an NRA should reflect a proportionate application of the “ladder of investment” principle, its effectiveness to induce the entrants to invest in their own NGA networks is quite ambiguous. Therefore, both the inclusion of a risk premium into the cost-based access price and the application of the “ladder of investment” theory seem to have ambiguous results. This implies that the basic principles of the EC Recommendation, which aims at initially encouraging the incumbents to invest in NGA networks without distorting competition and then at inducing the entrants to be facilities-based competitors, have been fiercely criticized in the related literature. However, the research articles study the impact of access prices on the investment incentives of either an incumbent or an entrant without taking into account that the investment decisions are taken in a sequential order, and hence, there is a strategic interaction between their investment decisions which is significantly affected by the regulatory policy.

For this reason, the next section presents an innovative approach that resolves the current regulatory trade-off between promoting service-based competition over copper access networks and encouraging the incumbent to invest in NGA networks, while also tackles the future trade-off between fostering service-based competition over NGA networks and incentivizing the entrants to invest in their own infrastructures. This approach is proposed by the following article which is also part of this thesis.

- M. Tselekounis, D. Varoutas, and D. Martakos, “A CDS approach to induce facilities-based competition over NGA networks,” *submitted to Telecommunications Policy* (under 3rd round revision), 2013. [31]

The motivation of the proposed approach, its modeling setup and its main conclusions are presented in the next section.

### 4.1.1 A CDS approach to induce facilities-based competition over NGA networks

The goal of this section is to propose a novel approach in order to effectively meet the current and the future regulatory goals using the regulatory settings recommended by the European Commission. The current regulatory framework in the European NGA market is described by the following four basic principles concerning:

- **The evolution of the regulatory goals over time.** The regulatory policy should initially encourage the incumbent to invest in new fibre-based access networks and promote service-based competition over such networks. Once the new fibre-based access network has been deployed and service-based competition over such networks has been established, the regulatory policy should encourage access seekers to invest in their own fibre infrastructures.
- **The characteristics of the access pricing formula.** The access to the incumbent’s network should be provided at cost-oriented prices including a risk premium to reflect any additional and quantifiable investment risk incurred by the investor. Risk allocation mechanisms, such as long-term contracts or volume discounts which decrease the risk that an investor incurs when investing in NGAs, lead to a respective decrease in the risk premium. However, since the EC Recommendation does not include in such mechanisms the fixed-fee payments, it is deduced that two-part access tariffs do not reflect the current regulatory framework in the European NGA market. Therefore, NRAs should apply usage (or uniform or linear) access prices under a regime of permanent regulation as long as an SMP operator is found within markets 4 and/or 5.
- **The evolution of the access prices.** Access prices should be aligned with the EC statement that the appropriate array of remedies imposed by an NRA

should reflect a proportionate application of the “ladder of investment” principle.

- **The provision of regulatory certainty.** According to the EC Recommendation, regulatory certainty is a key to promoting efficient investments by all operators. Applying a consistent regulatory approach over time is important to give investors confidence for the design of their business plans. In order to mitigate the uncertainty associated with periodical market reviews, NRAs should clarify to the greatest extent possible how foreseeable changes in market circumstances might affect remedies.

It is obvious that the literature studying the impact of access regulation on firms’ incentives to invest in NGA networks fail to take into account the basic principles governing the current regulatory framework in the European NGA market. The reason is that the reviewed research articles study the impact of alternative regulatory approaches on either the incumbents’ or the entrants’ investment incentives without considering the strategic interaction between their investment decisions. In other words, they do not take into account the fact that when the incumbent (respectively, the entrant) decides its optimal investment decision, it also considers the optimal investment reaction of the entrant (respectively, the incumbent). This implies that the disclosed access pricing policy should take into account the impact of access regulation on both firms’ incentives to invest although such investment decisions are taken in a sequential order.

To best of author’s knowledge, the only paper that reflects the current regulatory framework in terms of the evolution of the regulatory goals over time is that of Vareda [92]. In particular, Vareda considers a dynamic framework in which an incumbent chooses how much to upgrade the quality of its network and then an entrant, at each point in time, has the option to enter as a service-based competitor, by asking for access to the incumbent’s network, or as a facilities-based competitor, by building a bypass network. He shows that when the regulator can *ex ante* commit to a two-part access tariff: (i) the entrant’s investment in a bypass network is delayed with a higher incumbent’s investment in quality; (ii) the possibility of investment in a bypass network by the entrant has a positive effect on the incumbent’s incentive to upgrade quality; (iii) the effect of access prices on both incumbent and entrant firms’ incentives to invest is ambiguous; and (iv) a welfare improving access tariff that could be designed by the regulator would be one where the access fee is increasing (decreasing) in quality if the incumbent’s incentives are such that it underinvests (overinvests).

However, the work of Vareda not only uses a two-part access tariff (rather than a usage access price), but also assumes that the access price is fixed over time (rather than reflecting a proportionate application of the “ladder of investment” principle). Therefore, his model fails to align with two of the four basic principles of the EC Recommendation.

On the contrary, Tselekounis, Varoutas and Martakos [31] propose an innovative approach that reflects the current regulatory framework in the European NGA market as described by the EC Recommendation. In particular, the approach proposed by [31] models the four basic principles of the current European regulatory framework and then assesses its effectiveness on inducing facilities-based competition over NGA networks. This implies that this paper can be included in the literature that departs from assessing the efficiency outcomes of applying the regulation of the copper access networks to the NGA market. The aim of the proposed approach is to meet the current and the future regulatory goals by tackling the initial trade-off between encouraging the incumbents to invest in NGA networks and fostering competition, while incentivizing the entrants to gradually climb the ladder of investment when the NGA investment is proven to be successful. Therefore, the proposed approach provides a theoretical way to encourage the deployment of a nationwide NGA network (i.e. maximize the potential investment outcome in terms of geographic coverage) with the ambition that such deployment will finally reflect the socially desirable choice as reflecting in an effective migration path towards facilities-based competition over NGA networks.

The structure and the implementation of the proposed approach are based on the basic principles governing a Credit Default Swap (CDS). A CDS contract is an agreement between two parties, the protection buyer and the protection seller. The first party to the contract, the protection buyer, wishes to insure against the possibility of default on a bond issued by a particular company. The company that has issued the bond is called the reference entity. The second party to the contract, the protection seller, is willing to bear the risk associated with default by the reference entity. The protection buyer of the CDS makes a series of payments (the CDS "fee" or "spread") to the protection seller and, in exchange, receives a payoff in the event of a default by the reference entity. If a default does not occur over the life of the contract, the contract expires at its maturity date, and hence, the protection seller does not make any payments to the protection buyer.

In an NGA context, the incumbent, which is assumed to be the initial operator that invests in NGA networks, and the regulator agree on a business plan that allows the incumbent to recover the investment in a nationwide NGA deployment (i.e. the deployment of an NGA network in every geographic area in the country) during a certain period of time. If the investment has not been recovered at the end of this period, the regulator commits itself that it will compensate the incumbent for the unrecovered part of the investment. After the end of this period, no regulatory remedies will be imposed to the incumbent (sunset clause). In exchange, the incumbent should make periodic payments to the regulator. However, the regulator chooses to subtract this amount from the payments that an access seeker makes to the incumbent in order to have access to the NGA networks. This implies that the incumbent does not pay a periodic fee to the regulator but it subtracts this amount from the access payments it receives. If, however, the investment has been recovered before the end of the clause, the regulator does not make any payment to the incumbent, the incumbent stops making indirect periodic payments to the access seeker and no remedies imposed to the incumbent. In such contract, the incumbent is the protection buyer and the regulator is the protection seller which will compensate the incumbent in the case of a default event (i.e. if the investment has not been recovered at the end of the pre-determined period).

In addition, the model proposes that the contract commits the regulator to apply a certain policy during the whole pre-determined period. This policy, which concerns the derivation of the access pricing formula as well as its evolution over time, is *ex ante* known to the incumbent. As it has already been stated above, it is not optimal for the regulator to intervene in the market very often because it dilutes investment incentives. On the contrary, it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period. Thus, this model proposes an intermediate solution in which the regulator makes periodic reviews at a pre-determined period. In each periodic review, the regulator may increase or decrease the access price according to whether the

NGA investment (at the time of each review) is more successful (i.e. an upside case) or less successful (i.e. a downside case) than the initial estimations. It can thus be deduced that the incumbent invests in NGA networks under regulatory certainty.

It is shown that in an upside (respectively, downside) case, the implementation of the basic principles governing a CDS contract requires a proper increase (respectively, decrease) in the access price. Therefore, an endogenous access pricing rule encourages the entrants to climb the ladder of investment in each upside case (i.e. when the initial NGA investment by the incumbent is successful). On the contrary, such endogenous access pricing rule provides the entrants with disincentives to invest in each downside case. However, in the latter case, the regulator's goal is to increase the total demand rather than to incentivize the entrant to invest in NGA networks. The reason is that the entrant invests in NGA networks only when the NGA investment is successful. Therefore, the regulator should first promote the success of the NGA investment and then encourage the entrant to invest in its own facilities. It is obvious that in the downside cases the proposed approach fulfils in enhancing the diffusion process since a lower access price facilitates service-based competition over NGA networks. As a result, such an access pricing policy increases the probability of an upside case in the next regulatory review.

The authors believe that the proposed approach will eventually lead to the recovery of the NGA investment at the end of the pre-determined period or even earlier. After the end of the clause, the regulator does not make any payment to the incumbent, the latter stops making indirect periodic payments to the entrant and no regulatory remedies are imposed to the incumbent. This implies that the incumbent is free to set the access price to the recovered NGA networks. However, the entrant would have probably established a significantly high customer base, and hence, it will invest in the higher rungs of the investment ladder in order to be active in the market unless the incumbent prices the access too low in order to avoid intense facilities-based competition. The authors also discuss the case in which the NGA investment has not been recovered at the end of the pre-determined period, and hence, public funds are needed in order to compensate the incumbent for the unrecovered part of the NGA investment. They provide a theoretical cost-benefit analysis from a welfare perspective in order to show that, even in this case, the proposed approach is superior to the active governmental involvement in the deployment of a nationwide NGA network.

In conclusion, although its limitations and its potential implementation shortcomings, the proposed approach, which is based on the basic principles governing a Credit Default Swap (CDS), tackles the initial trade-off between encouraging the incumbent to invest in NGA networks and fostering competition, while it incentivizes the entrant to gradually climb the ladder of investment. This implies that the proposed approach represents an effective way towards facilities-based competition over NGA networks. In addition, the quite general approach of their paper also aims to trigger a fruitful open discussion about several economic and technical aspects of the optimal access pricing policy that should achieve both the current and the future regulatory goals.

### 4.2 Summary

This section provided a survey of the literature studying the impact of access regulation on an entrant's incentive to invest in its own access infrastructures in order to act as a facilities-based competitor to the incumbent. The main regulatory policy proposed to facilitate the migration from service-based to facilities-based competition is the "ladder of investment" theory which has attracted the interest of many academics and policy makers. However, this literature is based on the assumption that the incumbent has already deployed his NGA network, and hence, the implemented regulatory policy only affects the entrant's investment decisions. However, it is obvious that since facilities-based competition reflects the future regulatory goal, the disclosed regulatory policy which will be implemented in the future migration phase also affects the incumbent's incentives to invest the socially efficient outcome, which reflects the current regulatory goal.

For this reason, many aspects of the EC Recommendation should be reviewed taking into account the impact of current and future access regulation on the sequential investment decisions of an incumbent and an entrant. The second part of this section proposed an innovative approach that aims to provide an efficient migration path towards facilities-based competition over NGA networks by taking into account the current framework in the European NGA market.

It was shown that the proposed approach, which is based on the basic principles governing a CDS contract, can achieve the current and the future regulatory goals. In particular, it initially incentivizes the incumbent to deploy an NGA network and as service-based competition leads to higher demand for fibre-based services, it encourages the entrant to gradual invest in its own access infrastructures.

# 5. CONCLUSIONS AND FUTURE RESEARCH

The telecommunications industry is the most rapidly evolving network industry since it has undergone extensive changes in recent decades. Although these changes are mainly related to technological advancements, the regulatory policy has played a significant role in the promotion of competition and innovation.

From a static perspective, competition is related to the creation of a self-sustaining pro-competitive market structure in which firms have significant incentives to invest in innovative, differentiated services. Such service-based competition promotes both productive efficiency (i.e. existing assets are utilized efficiently) and allocative efficiency (i.e. existing resources are efficiently allocated to the economy). Therefore, consumers enjoy the welfare gains from static efficiency (lower prices, better quality and extended variety of services).

From a dynamic perspective, competition is related to the creation of a competitive market structure in which firms have significant incentives to invest in new network facilities. Such facilities-based competition leads to socially efficient investment decisions and the adoption of better technologies, which implies that consumers enjoy the welfare gains of dynamic efficiency (maximum market growth, minimized production cost, innovative technologies and advanced services).

It is thus obvious that the ultimate goal of regulators is to encourage all firms to undertake the socially optimal investment decisions in terms of both timing of investment and the extent of network deployment in order to promote dynamic efficiency. However, the initial market structure of the telecommunications sector, in which there was a state-owned monopoly (incumbent) operator, could not promote facilities-based competition. For this reason, the past regulatory goal was to reduce the incumbent's market power by allowing alternative operators (new entrants) to enter the market in order to effectively service-based compete with the incumbent. This implies that the promotion of dynamic efficiency is a long-run goal which will be gradually achieved in the telecommunications sector due to its innate asymmetric nature.

This thesis modeled the framework in the migration from a state monopoly market to a competitive telecommunications industry in order to study the impact of access prices on the entrant's incentives to undertake the efficient make-or-buy decision in terms of both productive and allocative efficiency. It was found that the particular model of competition that describes the competition in the retail market significantly affects the effectiveness of access prices to achieve static efficiency. However, cost-based access regulation, which was widely adopted by the regulatory authorities, was found to promote both productive and allocative efficiency regardless of the competition conditions. Therefore, theoretical modeling showed that usage cost-based prices achieve the past regulatory goal concerning the promotion of static efficiency.

Although dynamic efficiency seems to be the next regulatory goal once sustainable service-based competition over copper access networks has been established, the unambiguous positive impact of investments in new broadband infrastructures on economic growth and employment as well as the increasing need for bandwidth made national governments set as their first priority the encouragement of investments in fibre-based access networks (the so-called Next Generation Access (NGA) networks) rather than the promotion of dynamic efficiency. The reason is that investments in NGA infrastructures require a huge initial fixed cost, whereas the expected return is uncertain due to demand and regulatory risk factors. In other words, the current regulatory goal is to promote service-based competition over NGA networks rather than promote facilities-based competition over such networks.

It should be noted that the majority of the research articles studying the impact of access regulation of firms' investment incentives assumes that the incumbents rather than the entrants will eventually undertake NGA investments mainly due to their better economic situation. The related literature concludes that mandating access to NGA networks at usage cost-based prices discourages both incumbents and entrants to invest in such networks. Therefore, the research focuses on studying alternative regulatory schemes that may promote both investments and competition. These schemes deviate from the permanent regulation of access at usage cost-based prices in terms of the access pricing policy (i.e. non-cost-based access prices), the access pricing formula (i.e. non-usage access prices) and/or the regulatory regime employed (i.e. non-permanent regulation of access).

This literature strand concludes that such alternative regulatory schemes can induce the incumbent to undertake to socially optimal investments in NGA networks (i.e. promote both static and dynamic efficiency) under certain conditions concerning the demand and cost structure. However, these studies do not take into account the fact that regulators have a significant incentive to deviate from such schemes by setting a cost-based access price in order to maximize the efficiency outcomes once NGA networks have been deployed. This thesis modeled this fact in order to study the impact of regulatory uncertainty on an incumbent's incentives to undertake the efficient investments in NGA networks. It was found that the feasibility of the socially optimal outcome is not only affected by the demand and cost structure, but also by the perceived regulatory uncertainty.

A growing number of research studies propose a regulatory holidays regime (under which the investor is not imposed to any regulatory constraints for a pre-determined period of time) in order to maximize private investment incentives since although the social benefits from NGA deployment by far exceed the private incentive for investment, regulatory uncertainty and demand uncertainty undermine the expected profits. This thesis contributed to this literature by showing that a regulatory holidays regime may also improve social welfare if the monopolist is allowed to geographically price discriminate when the investment cost is not extremely low. However, even under the price discrimination regime, the monopolist underinvests compared to the socially optimal geographically differentiated NGA deployment.

It is thus obvious that although such alternative regulatory schemes may succeed in increasing both static and dynamic efficiency, the full welfare gains are achieved by facilities-based competition which reflects the long-run goal of the regulatory policy. As a result, the future regulatory goal is expected to be the migration from service-based to facilities-based competition over NGA networks. The literature studying the impact of access regulation on an entrant's incentives to invest in its own NGA networks (after the deployment of an NGA network by the incumbent) provides mixed results. In addition, it does not take into account that the disclosed regulatory policy in this migration phase affects the incumbent's investment decisions in the transition from service-based competition over copper access networks to service-based competition over NGA networks. This implies that the current and the future regulatory goals are closely related and a combined regulatory policy should be applied. This fact is also present in the EC Recommendation on regulated access to NGA networks which states that the access should be set at cost-based prices including an access markup for providing the initial investor with significant incentives, but such pricing scheme should also reflect a proportionate application of the ladder of investment principle in order to incentivize the access seekers to gradually invest in their own NGA infrastructures.

This thesis contributed to this literature by proposing an innovative regulatory approach which is based on the basic principles governing a CDS contract. It was shown that under quite general but plausible assumptions about demand and cost factors, the proposed approach can induce an efficient migration towards facilities-based competition over NGA networks. It is thus obvious that this thesis not only discussed the past, the present and the future state of telecommunications networks, but also significantly contributed to the literature which studies the optimal access pricing policy that achieves the past, the current and the future regulatory goals. Although this contribution provides significant results with clear policy implications, future research is needed in order to study the robustness of the derived results under different conditions and improve the proposed approaches by taking into account specific economic and technical aspects of NGA networks.

In particular, the contributed research articles in this thesis do not take into account the fact that the migration from copper access networks to NGA networks is a slow process [93]. This implies that even if fibre access networks replace much of the existing copper access infrastructures, there will be a period during which both are in operation and are competing for customers. Therefore, both the access prices for the copper and the NGA networks affect the final outcomes in terms of investment incentives and competition. Firstly, in the presence of a positive spillover of new investments, higher access prices increase the incumbent's opportunity cost of investment due to the wholesale revenue effect (if the incumbent invests in a higher quality network, the entrant will invest in reaction, and the incumbent will then lose some wholesale profits). Secondly, low access prices for the copper access networks increase the opportunity cost of the entrant's investment in NGA networks, making such investment less attractive, whereas low retail prices for the copper-based services discourage consumers to move from the old to the new technology unless the fibre-based services are priced sufficiently low as well [94]. The former effect is widely known as a "replacement effect" and the latter as a "business migration" effect. The fundamental point is that higher access prices lead to higher retail prices. Therefore, a higher difference between fibre and copper access prices implies a higher difference between fibre and copper retail prices, which, in turn, disincentivizes both entrant and consumers to move to the NGA networks. As a result, the impact of the regulation of the legacy network on the firms' investment incentives when the NGA market is left unregulated or when there is an interplay between the access prices of the two networks has recently attracted much attention and has been also studied by [95] and [96].

Another avenue for future research concerns the introduction of competition into the research articles that study a monopolist's incentives to undertake the socially optimal investments in NGA networks under geographic price discrimination. Such improvement will highlight the role of access regulation, whereas it will also trigger a discussion about the impact of wholesale price discrimination on the efficiency outcomes.

Last, the related literature, part of which are the contributed research articles in this thesis, implicitly or explicitly assumes that firms: (i) do not face capacity constraints; and (ii) make their optimal choices under fixed-coefficient technology with constant returns to scale. However, it is obvious that telecommunications networks have a limited capacity, whereas they are also closely related to modern technology which implies increasing returns to scale in production. Therefore, potential multiple equilibria and market failure may change the nature of access regulation.

# ABBREVIATIONS – ACRONYMS

| | |
|---|---|
| ADSL | Asymmetrical Digital Subscriber Line |
| CC | Current Costs |
| CDS | Credit Default Swap |
| CRTC | Canadian Radio-television and Telecommunications Commission |
| EC | European Commission |
| ECTA | European Competitive Telecommunications Association |
| ESON | Ethernet Switched Optical Network |
| ETNO | European Telecommunications Network Operators' Association |
| EU | European Union |
| FCC | Federal Communications Commission |
| FDC | Fully Distributed/Allocated Cost |
| FTTC | Fibre-to-the-Curb |
| FTTH | Fibre-to-the-Home |
| GDP | Gross Domestic Product |
| GPON | Gigabit Passive Optical Network |
| HC | Historic Costs |
| LLU | Local Loop Unbundling |
| LRAIC | Long Run Average Incremental Cost |
| LRIC | Long Run Incremental Cost |
| MC | Marginal Cost |
| NGA/NGAN | Next Generation Access Networks |
| NRA | National Regulatory Authority |
| OECD | Organization for Economic Co-operation and Development |
| P2P(E) | Point-to-Point (Ethernet) |
| PSTN | Public Switched Telephone Network |
| SAC | Stand-Alone Cost |
| SMP | Significant Market Power |
| TELRIC | Total Element Long Run Incremental Cost |
| TSLRIC | Total Service Long Run Incremental Cost |
| US | United States (of America) |
| VDSL | Very high-bit-rate Digital Subscriber Line |
| WACC | Weighted Average Cost of Capital |
| OTE | Hellenic Telecommunications Organization |

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# APPENDIX A

The research towards the completion of this thesis led to the publication of six original articles that are at the centre of the literature studying the optimal regulatory intervention in each migration phase during the evolution of the telecommunications networks. Appendix A quotes these articles as they have been originally published in refereed international journals or including in the proceedings of refereed international conferences.

**M. Tselekounis, D. Varoutas, and D. Martakos, “On the social optimality of make-or-buy decisions,” *Journal of Regulatory Economics*, vol. 41, no. 2, pp. 238–268, Sep. 2012.**

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ORIGINAL ARTICLE

# On the social optimality of make-or-buy decisions

**Markos Tselekounis · Dimitris Varoutas · Drakoulis Martakos**

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**Abstract** This article examines the impact of input prices on an entrant's make-or-buy decision and on the subsequent social welfare level for three alternative models of downstream competition. For each particular model, it derives the range of input prices that induce the entrant to undertake: (a) the productively efficient make-or-buy decision; and (b) the socially optimal make-or-buy decision. The main conclusion of this article is that the entrant's efficient make-or-buy decision is always socially optimal in the case of the Hotelling model, is socially optimal for the set of input prices that induce the entrant to undertake the efficient decision in the case of Cournot competition and is not necessarily socially optimal in the Bertrand vertical differentiation model. Last, this article examines the conditions under which the efficient and/or socially optimal make-or-buy decision undertaken by an entrant fulfills the regulatory two-fold goal of promoting service-based competition and encouraging facilities-based competition. Therefore, this article also provides the optimal access pricing policy that results in the best feasible outcome in terms of social welfare, productive efficiency, competition level and investment level for a given downstream competition model.

**Keywords** Access regulation · Downstream competition · Investment incentives · Productive efficiency · Social welfare · Telecommunications

**JEL Classification** L43 · L51 · L96

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## 1. Introduction

The Telecommunications Act of 1996 authorized new suppliers (entrants) of telecommunications services to have access to incumbent suppliers' key network elements at cost-based prices. The purpose of this policy is "to promote competition and reduce regulation in order to secure lower prices and higher quality services for (American) telecommunications consumers and encourage the rapid deployment of new telecommunications technologies". Hence, the ultimate goal of this unbundling policy is twofold. First, it aims at inducing service-based competition in the downstream (retail) market which leads to lower prices, higher quality and higher social welfare. Second, once service-based competition has been established, it aims at promoting facilities-based competition which leads to innovation and market growth. Service-based competition requires mandated access to the incumbent network, whereas facilities-based competition requires investment in network infrastructure by incumbents and, especially, entrants.

The promotion of service-based competition is mainly based on cost-oriented input (or access) prices, and especially on LRIC (Long-Run Incremental Cost) methodology.[1] The main advantage of this methodology is that it provides the new entrants with significant incentives to enter the market and, as a result, the consumers enjoy the short-run benefits from service-based competition. On the contrary, the main drawback of this methodology is that it discourages both incumbents and new entrants to invest in new access infrastructures (the so-called Next Generation Access networks, or NGA).

Indeed, Jorde et al. (2000) study the impact of cost-based input prices on the incumbents' incentives to upgrade their access network and find that the input prices based on LRIC methodology discourage incumbents to invest. Ingraham and Sidak (2003) confirm empirically the result of Jorde et al. (2000). According to Cave and Prosperetti (2001), the reason for this negative relationship between access regulation and incumbents' investment incentives is that input prices based on LRIC discourage incumbents to invest in networks because they anticipate that they will be required to offer access to their rivals at cost-based prices.

In addition, Jorde et al. (2000) show that regulating input prices based on LRIC methodology encourages entrants to deviate from the socially optimal investment level and to delay entry. Furthermore, Bourreau and Dogan (2006) show that unbundling of the local loop may delay facilities-based competition, even in an unregulated environment.

Therefore, cost-based input prices cannot induce both effective competition and investments in new access networks. One of the most known theories for tackling this trade-off is the so called "ladder of investment theory" proposed by Cave and Vogelsang (2003). This theory is based on the fact that entrants will typically invest in replicable assets first and then progress to less replicable ones. Thus, it suggests that at the initial stage of competition the input price for the less replicable network elements should be low but increasing over time as assets are replicated. Although this theory has been fiercely criticized by Crandall et al. (2004) and Hazlett and Bazelon (2005), the EC Recommendation on regulated

[1] See Armstrong (2002) and Valletti and Estache (1998) for an excellent and extensive review of the literature on access pricing.

access to NGA (EC, 2010)[2] stresses that the appropriate array of remedies imposed by an NRA should reflect a proportionate application of the ladder of investment theory.

The papers closest to ours are Sappington (2005) and Gayle and Weisman (2007a) which study the impact of different downstream interactions on a new entrant's profits when it purchases an essential upstream input from the incumbent and when it makes the upstream input itself. In particular, Sappington (2005) uses the standard Hotelling (1929) model of downstream competition to show that input prices are irrelevant for an entrant's decision to make or buy an input required for downstream production. This result is striking since it negates most of the aforementioned studies concluding that cost-based input prices promote effective competition but discourage both incumbents and new entrants to invest in new access infrastructures.

According to Sappington, the reason for this result is that previous studies fail to take into account the impact of a new entrant's make-or-buy decision on subsequent retail price competition. When the incumbent sells an upstream input to the new entrant, the incumbent faces an opportunity cost of expanding its retail output. The incorporation of this opportunity cost into the incumbent's total cost makes the incumbent act as if its upstream cost of production were equal to the specified input price. Therefore, regardless of the input price, the entrant will choose to buy (respectively, make) the upstream input whenever the incumbent (respectively, entrant) has an innate upstream cost advantage. Therefore, the entrant's decision always minimizes industry costs and ensures efficient entry and utilization of the telecommunications infrastructure. Thus, the entrant always undertakes the efficient make-or-buy decision.

After Sappington's suggestion, Gayle and Weisman (2007a) consider alternative downstream interactions and show that input prices are not necessarily irrelevant in the Bertrand vertical differentiation model and are not irrelevant in the Cournot model. This implies that departure from cost-based input prices may distort the efficiency of the entrant's make-or-buy decision.

As a result, Sappington (2005) and Gayle and Weisman (2007a) study the impact of input prices on the efficiency of the entrant's make-or-buy decisions. This paper studies the impact of input prices on the social optimality of the entrant's make-or-buy decisions under the alternative theoretical settings of Sappington (2005) and Gayle and Weisman (2007a). First, we make explicit the Sappington's conjecture that regardless of the established price of the upstream input, the entrant always undertakes the make-or-buy decision that is not only efficient, but also socially optimal. Second, we explore the robustness of this result in the Bertrand vertical differentiation model and in the Cournot model. We find that the social optimality of the entrant's make-or-buy decision is affected by two crucial factors: (a) the particular level of the price of the upstream input; and (b) the cost differential between the incumbent's and the entrant's unit costs of producing the upstream input. For this reason, we obtain the range of both input prices and upstream cost differential that induce the entrant to undertake the socially desirable decision.

By combining our results with those of Sappington (2005) and Gayle and Weisman (2007a), we show that the entrant's efficient make-or-buy decision is always socially optimal in the case of Hotelling, is socially optimal for the set of

[2] http://ec.europa.eu/information_society/policy/ecomm/doc/library/recomm_guidelines/nga/en.pdf

input prices that induce the entrant to undertake the efficient decision in the case of Cournot competition and is not necessarily socially optimal in the Bertrand vertical differentiation model. Therefore, we make regulatory implications concerning the range of input prices that tackle the regulatory trade-off, while (cannot) result in the most efficient outcome.

The rest of the paper is organized as follows. Section 2 gives an outline of the basic assumptions and definitions. Section 3 presents the main findings concerning the impact of input prices on the social optimality of make-or-buy decisions in the Hotelling model, in the Cournot model and in the Bertrand vertical differentiation model. The last section compares the results of the three models, summarizes the key findings and makes regulatory implications. The proofs of all assumptions, lemmas and propositions are in the Appendix A.

## 2. Assumptions and definitions

We consider a duopoly case where two suppliers compete according to a particular model of downstream competition. Each unit of the downstream service requires one unit of the upstream input and one unit of the downstream input. Each firm supplies its own downstream input. The unit costs of producing the downstream input are $c_d^I$ and $c_d^{\mathrm{E}}$ for the incumbent and the entrant, respectively. Without loss of generality, we further assume that the unit cost of producing the downstream input is the same for the two retailers and is set to zero. The incumbent and entrant's unit costs of producing the upstream input are denoted by $c_u^I$ and $c_u^{\mathrm{E}}$, respectively.

The entrant has to decide between buying the upstream input from the incumbent at a regulated price *w* and making the upstream input itself. The entrant is understood to make the efficient make-or-buy decision if it purchases the input from the incumbent when the incumbent is the least-cost supplier ($c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$) and produces the input itself whenever it is the least-cost supplier ($c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$). In addition, the entrant is understood to make the socially optimal make-or-buy decision if it chooses to buy (respectively, make) the upstream input when this decision leads to higher social welfare level than its decision to make (respectively, buy) the upstream input. The timing of the game is as follows. First, the regulator sets the input price *w*. After observing the input price, the entrant decides whether it will buy the upstream input from the incumbent or produce it itself. Last, the two providers choose their retail prices that maximize their profits.

We use the backward induction method to find the equilibrium of the whole game. Therefore, the analysis begins with the computation of the retail price and the outputs of the firms. Then, using these results, the entrant undertakes its make-or-buy decision, which depends on the regulated input price. Finally, based on the previous information, the regulator sets the input price that induces the entrant to undertake the best feasible outcome in terms of social welfare, productive efficiency, competition level and investment level. In this paper, we examine the impact of input prices on each regulatory goal for three alternative models of downstream competition: Hotelling model, Cournot model and Bertrand vertical differentiation model.

# 3. Findings

## 3.1 Hotelling model

The two rivals, whose final services are differentiated á la Hotelling (1929), are located at the two extremities of the market. In particular, the incumbent is located at point $L^I = 0$ and the entrant is located at point $L^E = 1$. *N* consumers are uniformly distributed on the unit interval [0,1]. Consumers are endowed with utility $U_L(L^i, P^i) = v - P^i - t\left|L^i - L\right|$ where locations $(L^i)$ and prices $(P^i)$ for the incumbent and the entrant are denoted by the superscript *I* and *E*, respectively, i.e. $i = I, E$. The term $t\left|L^i - L\right|$ can be interpreted as the disutility which the consumer located at point $L \in [0,1]$ incurs through the distance of transport. The first term, $v > 0$, can be interpreted as the reservation price and it is assumed that it exceeds the sum of price and transport cost in order to ensure that each consumer buys one unit of the final service. Note that consumer utility $U_L$ has a maximum where the consumer's location *L* and the firm's location coincide.

Sappington (2005) discusses the entrant's make-or-buy decision by comparing the entrant's profits when it decides to buy the upstream input from the incumbent ($\Pi_B^E$) with its profits when it chooses to make the upstream input itself ($\Pi_M^E$). His main finding is stated in proposition 1:

**Proposition 1 (Sappington, 2005).** *Regardless of the established price (w) of the upstream input: (a) the entrant prefers to buy the upstream input from the incumbent when the incumbent is the least-cost supplier of the input (i.e.* $\Pi_B^E > \Pi_M^E$ if $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$); *and (b) the entrant prefers to make the upstream input itself when it is the least-cost supplier of the input (i.e.* $\Pi_{\mathrm{M}}^E > \Pi_{\mathrm{B}}^E$ if $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$).

From proposition 1 we infer that input prices are irrelevant for the entrant's make-or-buy decision. In addition, it is obvious that the entrant's decision always results in the most efficient outcome. Hence, regardless of the established price of the upstream input, the entrant always undertakes the efficient make-or-buy decision. Furthermore, we show in the Appendix A1[3] that input prices do not have an impact on social welfare.[4] Therefore, input prices are irrelevant not only for the entrant's efficient make-or-buy decision, but also for the regulator's goal to maximize social welfare. The reason is that a marginal increase (decrease) in the input price causes a unit increase (decrease) in the incumbent's profits and a unit decrease (increase) in consumer surplus. As social welfare is the unweighted sum of industry profits and consumer surplus, it is thus not affected by a marginal change in input prices.

However, our primary goal is to examine the social optimality of the entrant's efficient make-or-buy decision. Thus, we compare the social welfare level obtained when the entrant chooses to buy the upstream input ($SW_B$) to the

[3] See equation (A13).

[4] Shim and Oh (2006) also state that the level of the input price does not affect the entrant's profits and the total social surplus. However, they do not combine this result with the entrant's efficient make-or-buy decision.

respective level of social welfare obtained when the entrant chooses to make the upstream input itself ($SW_M$). We can then state the following proposition:

**Proposition 2.** *Regardless of the established price (w) of the upstream input: (a) the entrant's decision to buy the upstream input from the incumbent is socially optimal when the incumbent is the least-cost supplier of the input (i.e. $SW_B > SW_M$ if $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$); and (b) the entrant's decision to make the upstream input itself is socially optimal when it is the least-cost supplier of the input (i.e. $SW_M > SW_B$ if $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$).*

Combining propositions 1 and 2 concludes that the entrant's decision to buy the upstream input from the incumbent if $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$ and to make the upstream input itself if $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$, is not only efficient, but also socially optimal. Hence, the maximization of social welfare is in line with the entrant's efficient make-or-buy decision.

**Proposition 3.** *In the equilibrium of the Hotelling model, the efficient make-or-buy decision undertaken by the entrant is always socially optimal.*

Proposition 3 presents a significant finding: although access price regulation affects neither the efficient make-or-buy decision undertaken by the entrant nor the level of social welfare, the regulator always succeeds in fulfilling the maximization of social welfare by not intervening in the upstream market. When $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$ the entrant chooses to make the upstream input and, as a result, it invests in alternative infrastructures, which is socially optimal. In this case, the absence of access price regulation tackles the trade-off between service-based and facilities-based competition. Thus the regulator's twofold aim is fulfilled. On the contrary, when $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$ the entrant chooses to buy the upstream input from the incumbent, which is also socially optimal. In this case, the society only enjoys the short-run benefits from service-based competition.

### 3.2 Cournot model

The two rivals, whose final services are homogeneous, choose their optimal amount of output they will produce independently and simultaneously. The inverse demand function is given by $P(Q) = A - BQ$, where $P(Q)$ is the retail market price, $A > 0$ is the reservation price, $B > 0$ is the slope of the inverse demand function and $Q = Q^I + Q^E$ is market output, where $Q^I$ and $Q^E$ denote the incumbent and the entrant's output, respectively.

Gayle and Weisman (2007a) discuss the impact of input prices on the entrant's make-or-buy decision by comparing the entrant's profits when it decides to buy the upstream input from the incumbent with its profits when it chooses to make the upstream input itself. Their main finding is stated in proposition 4:

**Proposition 4 (Gayle and Weisman, 2007a).** *In the equilibrium of the Cournot model: (a) The entrant makes the input rather than buys the input from the incumbent when* $c_u^{\mathrm{E}} < w$; and *(b) The entrant buys the input from the incumbent when* $c_u^{\mathrm{E}} > w$.

From proposition 4, it can be deduced that input prices are not irrelevant for the entrant's make-or-buy decision. In addition, the entrant's decision results in the most efficient outcome when $c_u^{\mathrm{E}} < \min\{w, c_u^I\}$ or $c_u^{\mathrm{E}} > \max\{w, c_u^I\}$. Therefore, there is a potential efficiency distortion in the make-or-buy decision and hence input prices are not irrelevant. Concerning the impact of input prices on social welfare, we find that that the society is indifferent about the entrant's decision to make or buy the upstream input when:

$$6(c_u^I)^2 - 14(c_u^I)(c_u^E) - 4(c_u^I)w + 6A(c_u^I) + 11(c_u^E)^2 - 8A(c_u^E) + w^2 + 2Aw = 0 \tag{1}$$

By solving equation (1) with respect to *w*, the optimal input price ($w^*$) that makes the society be indifferent about the entrant's make-or-buy decision is derived: [5]

$$w^* = -A + 2(c_u^I) + \sqrt{A^2 + 14(c_u^I)(c_u^E) - 11(c_u^E)^2 + 8A(c_u^E) - 10A(c_u^I) - 2(c_u^I)^2} \tag{2}$$

**Proposition 5.** *(a) The entrant's decision to buy the upstream input from the incumbent is socially optimal when* $w < w^*$*; and (b) the entrant's decision to make the upstream input itself is socially optimal when* $w > w^*$.

By combining propositions 4 and 5, it is deduced that the entrant's decision is always socially optimal when $c_u^{\mathrm{E}} = w^*$. Therefore, for any $w^* \neq c_u^{\mathrm{E}}$ there is a potential social welfare distortion in the make-or-buy decision and hence input prices may not be irrelevant. For this reason, we derive the set of input prices that induce the entrant to undertake the socially optimal make-or-buy decision. Then, we examine whether the entrant's efficient make-or-buy decision is also socially optimal. It is instructive to limit our study to the range of input prices for which a Nash equilibrium exists:

**Assumption 1.** Let (α) $A^2 + 14(c_u^I)(c_u^E) - 11(c_u^E)^2 + 8A(c_u^E) - 10A(c_u^I) - 2(c_u^I)^2 \geq 0$; (b) $w \leq \overline{w} = (A + c_u^I)/2$; and (c) $w \geq \underline{w} = [-5(A + c_u^I) + 3\sqrt{5}(A - c_u^I)]/(-10)$.

The first constraint ensures that $w \in \mathbb{R}^+$, the second one that the entrant is active when it buys the upstream input from the incumbent (i.e. $Q_{\mathrm{B}}^E \geq 0$) and the third one that the incumbent's profits are non-negative when it sells the upstream input

[5] The second solution of equation (1) is rejected because it leads to negative input prices (see Appendix A2).

to the entrant (i.e. $\Pi_B^I \geq 0$).[6] Therefore the second inequality provides the highest input price ($\overline{w}$) at which a Nash equilibrium exists, whereas the third inequality provides the lowest input price ($\underline{w}$) at which a Nash equilibrium exists.

Since $w^*$ is affected by both $c_u^I$ and $c_u^E$, we should discriminate between three cases regarding the upstream cost differential in order to derive the set of input prices that induce the entrant to undertake the socially optimal make-or-buy decision.

### *3.2.1 Neither provider has an innate upstream cost advantage*

In this case, the unit cost of producing the upstream input is the same for the two retailers, that is $c_u^I = c_u^E$. Substituting $c_u^I = c_u^E$ into equation (2) gives the optimal input price ($w^*$) that makes the society be indifferent about the entrant's make-or-buy decision.

**Lemma 1.** *If* $c_u^I = c_u^E$ *then* $\underline{w} < c_u^I = c_u^E = w^* < \overline{w}$.

Figure 1 presents a graphical analysis of propositions 4 and 5 for the case described in lemma 1.

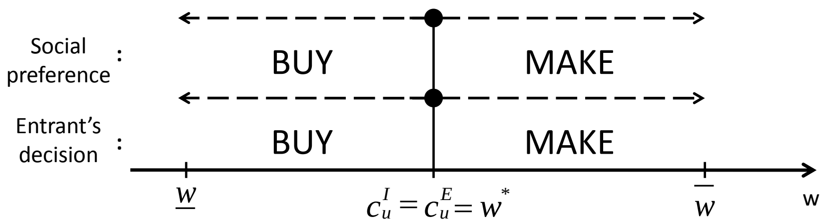


**Fig. 1** The effect of input prices on the social optimality of make-or-buy decisions when neither provider has an upstream cost advantage

It is deduced that when neither provider has an innate upstream cost advantage: (a) the entrant's decision to buy the upstream input from the incumbent is socially optimal when $w < c_u^E$; and (b) the entrant's decision to make the upstream input itself is socially optimal when $w > c_u^E$. We conclude that the entrant's decision to make or buy the upstream input is always socially optimal when neither provider has an innate upstream cost advantage. However, the fulfillment of the regulator's two-fold goal requires the regulator to set the input price at a higher level than the providers' unit cost of producing the upstream input. Therefore, it is obvious that the optimal regulatory policy is to induce the entrant to produce the upstream input itself.

### *3.2.2 The entrant has an innate upstream cost advantage*

[6] Another necessary constraint to ensure that $\Pi_B^I \geq 0$ is $w \leq \overline{\overline{w}} = [-5(A+c_u^I) - 3\sqrt{5}(A-c_u^I)]/(-10)$. However, the second constraint of the first assumption is sufficient to ensure that $w \leq \overline{\overline{w}}$ (See Appendix A2).

In this case, the entrant is more efficient than the incumbent in producing the upstream input, that is $c_u^E < c_u^I$. We should calculate the optimal input price ($w^*$) in order to derive the set of input prices that induce the entrant to undertake the socially optimal make-or-buy decision. The impact of the entrant's upstream cost advantage on the optimal input price ($w^*$) is described by the following Lemma:

**Lemma 2.** (a) If $(c_u^E)' < c_u^E < c_u^I$ then $\underline{w} < w^* < c_u^E < c_u^I < \overline{w}$; and (b) if $c_u^E < (c_u^E)' < c_u^I$ then $w^* < \underline{w} < c_u^E < c_u^I < \overline{w}$, where $(c_u^E)' = \dfrac{4A + 7c_u^I}{11} - (A + c_u^I)\sqrt{\dfrac{198\sqrt{5} - 54}{5}}$ .

Figure 2 presents a graphical analysis of propositions 4 and 5 for each of the two cases described in lemma 2.

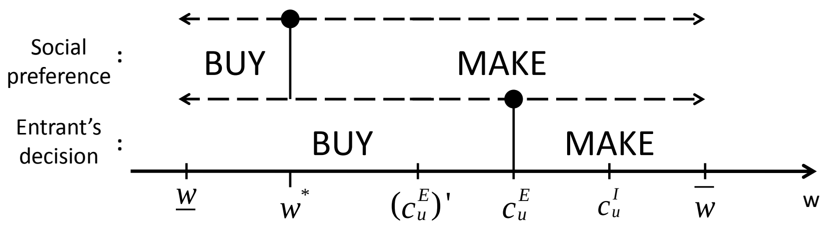


**Fig. 2(a)** The effect of input prices on the social optimality of make-or-buy decisions when the entrant is not much more efficient than the incumbent

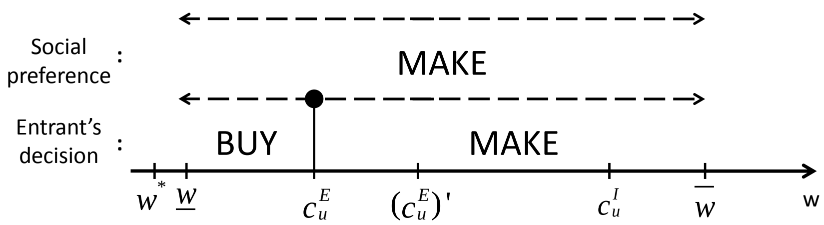


**Fig. 2(b)** The effect of input prices on the social optimality of make-or-buy decisions when the entrant is much more efficient than the incumbent

A number of observations derived by the analysis of figure 2 are instructive. First when the upstream cost differential is low enough, the socially optimal decision for the entrant is to make the upstream input even for relative low input prices, whereas when the upstream cost differential is high enough, the socially optimal decision for the entrant is to make the upstream input regardless of the input price. The rationale of this result is that the more efficient the entrant is in producing the upstream input, the larger the range of input prices that lead the society to prefer the entrant to make the upstream input. As a result, a low (respectively, high) enough upstream cost differential causes input prices to be relevant (respective, irrelevant) for the impact of an entrant's make-or-buy decision on social welfare. Second, an entrant's make-or-buy decision is socially optimal when (a) $w < w^*$ or $w > c_u^E$ for $(c_u^E)' < c_u^E < c_u^I$; and (b) $w > c_u^E$ for $c_u^E < (c_u^E)' < c_u^I$. This implies that there is a potential distortion of the social optimality of make-or-buy decisions. Third, regardless of the upstream cost differential, an entrant's efficient make-or-buy decision is always socially optimal. Indeed, the entrant is understood to make the efficient make-or-buy decision if it produces the input itself since it is the least-cost supplier ($c_u^E < c_u^I$). Therefore, the entrant undertakes the efficient make-or-buy decision if $w > c_u^E$, which also leads to the socially optimal outcome.

In conclusion, the entrant's efficient decision not only leads to the socially optimal outcome, but also tackles the trade-off between fostering effective competition and encouraging investments in new access infrastructures. Thus, the regulator should set $w > c_u^E$.

### *3.2.3 The incumbent has an innate upstream cost advantage*

In this case, the incumbent is more efficient than the entrant in producing the upstream input, that is $c_u^E > c_u^I$. Like the case in which the entrant had an innate upstream cost advantage, we should calculate the optimal input price ($w^*$) in order to derive the set of input prices that induce the entrant to undertake the socially optimal make-or-buy decision. The impact of the incumbent's upstream cost advantage on the optimal input price ($w^*$) is described by the following Lemma:

**Lemma 3.** (a) If $c_u^I < c_u^E < (c_u^E)''$ then $\underline{w} < c_u^I < c_u^E < w^* < \overline{w}$; and (b) if $(c_u^E)'' < c_u^E \leq \overline{w}$ then $\underline{w} < c_u^I < c_u^E < \overline{w} \leq w^*$, where $(c_u^E)'' = \dfrac{5A + 17c_u^I}{22}$.

Figure 3 presents a graphical analysis of propositions 4 and 5 for each of the two cases described in lemma 3.

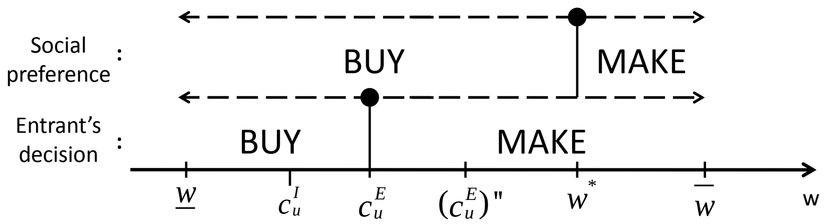


**Fig. 3(a)** The effect of input prices on the social optimality of make-or-buy decisions when the incumbent is not much more efficient than the entrant

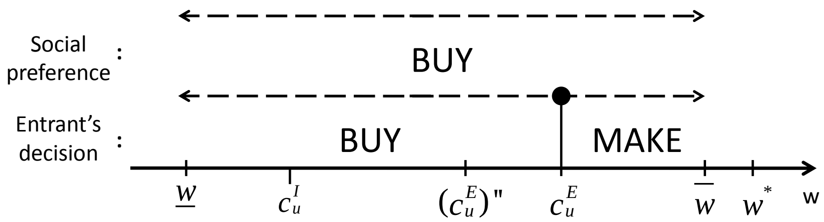


**Fig. 3(b)** The effect of input prices on the social optimality of make-or-buy decisions when the incumbent is much more efficient than the entrant

From figure 3, it is deduced that when the upstream cost differential is low enough, the socially optimal decision for the entrant is to buy the upstream input even for relative high input prices, whereas when the upstream cost differential is high enough, the socially optimal decision for the entrant is to buy the upstream input regardless of the input price. The rationale of this result is that the more efficient the incumbent is in producing the upstream input, the larger the range of input prices that lead the society to prefer the entrant to buy the upstream input. As a result, a low (respectively, high) enough upstream cost differential causes input prices to be relevant (respective, irrelevant) for the impact of an entrant's make-or-buy decision on social welfare. Another significant deduction is that an entrant's make-or-buy decision is socially optimal when (a) $w > w^*$ or $w < c_u^E$ for $c_u^I < c_u^E < (c_u^E)''$; and (b) $w < c_u^E$ for $(c_u^E)'' < c_u^E \le \overline{w}$. This implies that there is a potential distortion of the social optimality of make-or-buy decisions. Last, regardless of the upstream cost differential, an entrant's efficient make-or-buy decision is always socially optimal. Indeed, the entrant is understood to make the efficient make-or-buy decision if it purchases the input since the incumbent is the least-cost supplier ($c_u^E > c_u^I$). Therefore, the entrant undertakes the efficient make-or-buy decision if $w < c_u^E$, which also leads to the socially optimal outcome.

However, the social optimality of facilities-based competition is fulfilled only when the upstream cost differential is low enough, the regulated access price is relative high ($w > w^*$) and, of course, at the cost of the productive efficiency. In this case there is another trade-off between the productive efficiency and the social optimality of make-or-buy decisions.

### *3.2.4 Discussion*

Given that the downstream competition is characterized by the Cournot model, the analysis of the impact of input prices on social welfare shows that regardless of which provider has an innate upstream cost advantage, input prices are (not) irrelevant for the social optimality of the entrant's make-or-buy decision when the upstream cost differential is high (low) enough.

In addition, although the absence of access price regulation always leads to the socially optimal make-or-buy decision in the case of Hotelling, regulatory intervention is necessary in order to induce the entrant to undertake the socially optimal make-or-buy decision in the case of the Cournot competition. This implies that there is a potential distortion in the social optimality of make-or-buy decisions and especially in the fulfillment of the regulator's twofold goal.

However, the main conclusion of the analysis of the entrant's make-or-buy decision from a social perspective is that the entrant's efficient decision is always socially optimal. Therefore, we can state the following proposition:

**Proposition 6.** *In the equilibrium of the Cournot model, the efficient make-or-buy decision undertaken by the entrant is always socially optimal.*

Proposition 6 states that when $c_u^E < c_u^I$ (respectively, $c_u^E > c_u^I$), the entrant's decision to make (respectively, buy) the upstream input not only leads to the most efficient outcome, but also to the socially optimal one. It is worth noting, that in the Hotelling model, as well as, in the Cournot model, the entrant's efficient make-or-buy decision is always socially optimal. However, in the former case the social optimality of the efficient make-or-buy decisions is fulfilled without any regulatory intervention in the upstream market, whereas in the latter case the regulatory intervention is necessary for ensuring such optimality. In particular, the regulator should set $w > c_u^E$ if $c_u^E < c_u^I$ and $w < c_u^E$ if $c_u^E > c_u^I$ in order to ensure the social optimality of the efficient make-or-buy decision undertaken by the entrant. Any deviation from this regulatory policy may result in a socially optimal outcome which is not efficient, or to an entrant's decision that is not socially optimal.

Therefore, we demonstrate a continuum of findings in which, depending of the input prices, the entrant's make-or-buy decision is both efficient and socially optimal, is only socially optimal and is neither efficient nor socially optimal.

### 3.3 Bertrand vertical differentiation model

In the Bertrand vertical differentiation model, the final products of the two rivals can be ordered in an objective way according to their perceived difference in quality. In this paper, it is assumed that the incumbent produces the high quality good and the entrant produces the lower quality good. Like Gayle and Weisman (2007a), we assume that a consumer requires only one unit of the product and her indirect utility for the high quality good is given by, $V_h = \theta\lambda_h - p_h$, while her indirect utility for the low quality good is given by, $V_l = \theta\lambda_l - p_l$, where $\lambda_h > \lambda_l$. Each consumer has a unique $\theta$, which captures taste heterogeneity in the population and is assumed to be uniformly distributed on the interval [0, 1].Without loss of generality, we also normalize the population of consumers to 1.

Gayle and Weisman (2007a) discuss the impact of input prices on the entrant's make-or-buy decision by comparing the entrant's profits when it decides to buy the upstream input from the incumbent with its profits when it chooses to make the upstream input itself. Their main finding is stated in proposition 7:

**Proposition 7 (Gayle and Weisman, 2007a).** *In the equilibrium of the Bertrand vertical differentiation model: (a) The entrant makes the input rather than buys from the incumbent when* $c_u^E < c_u^I$ *for* $w \geq c_u^E$*; and (b) The entrant buys the input from the incumbent if and only if* $c_u^E > c_u^I$ *and* $(2\lambda_h - \lambda_l)(w - c_u^E) < \lambda_l(w - c_u^I)$*.*

The main conclusion of the above proposition is that when the entrant is (not) the least-cost supplier, its make-or-buy decision is (not) independent of input prices in a Bertrand framework. Therefore, input prices are not necessarily irrelevant in the Bertrand vertical differentiation model. This implies that there is a potential efficiency distortion in the make-or-buy decision. In this paper, we examine the impact of input prices on social welfare when the entrant chooses to buy the upstream input from the incumbent and when it chooses to make the upstream input itself. Therefore, we should compare the level of social welfare when an entrant purchases an essential upstream input from the incumbent to the respective level of social welfare when an entrant makes the upstream input itself. The results of this comparison can be summarized in the following proposition:

**Proposition 8.** *(a) The entrant's decision to buy the upstream input from the incumbent is socially optimal when $w < w^{**}$; and (b) the entrant's decision to make the upstream input itself is socially optimal when $w > w^{**}$, where $w^{**}$ represents the input price that makes the society be indifferent about the entrant's decision to make or buy the upstream input.* [7]

From proposition 8, we deduce that input prices are not irrelevant for the maximization of social welfare and, as a result, for the social optimality of the entrant's make-or-buy decision. However, the main goal of this paper is not to show that input prices are not irrelevant for the maximization of social welfare, but (a) to find the conditions under which the entrant's make-or-buy decision is socially optimal; and (b) to provide the set of input prices that induce the entrant to undertake not only the socially optimal decision but also the most efficient one. Thus, we should combine the results of propositions 7 and 8.

The main part of the analysis that follows is conducted via numerical simulations due to the complexity of closed-form solutions for the endogenous variable $w^{**}$. Therefore, we use numerical examples in order to derive the equilibrium results. Like in the case of the Cournot model, we discriminate between three main cases: (a) neither provider has an innate upstream cost advantage; (b) the entrant has an innate upstream cost advantage; and (c) the incumbent has an innate upstream cost advantage.

The analysis conducted is similar to Gayle and Weisman (2007a) and Gayle and Weisman (2007b) with the exception that this paper takes into account the impact of the upstream cost differential on the entrant's make-or-buy decision and, as a result, on the subsequent social welfare level. In other words, we examine the social optimality of make-or-buy decisions for many combinations of the incumbent's and the entrant's unit costs of producing the upstream input rather than fixing arbitrarily their upstream unit costs. For each combination, we estimate the input prices that cause (a) the society; and (b) the entrant, to be indifferent between the latter's decision to make or buy the upstream input ($w^{**}$ and $w_e = [(2\lambda_h - \lambda_l)c_u^E - \lambda_l c_u^I] / 2(\lambda_h - \lambda_l)$, respectively). The results are presented in Table 1 (Appendix B).

Note that when the entrant chooses to buy the upstream input, the curve that represents its profits ($\Pi_B^l$) is a convex and decreasing function of *w*, whereas the curve that represents the social welfare ($SW_B$) is a concave and decreasing function of *w.* Since the entrant's profits and the social welfare are not affected by input prices when the entrant chooses to make the upstream input itself, the respective curves $\Pi_M^l$ and $SW_M$ are horizontal lines. In this numerical example the incumbent's upstream cost of providing the upstream input is fixed at 0.55. Therefore, we assume different values of the entrant's upstream cost of providing the upstream input in order to study the effect of both upstream cost differential and input prices on the social optimality of make-or-buy decisions.

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[7] It is worth noting that the value of $w^{**}$ depends on the model's parameters, as described in the Appendix A3. In some special cases, which are also described in the Appendix A3, there are two positive input prices that cause $SW_M = SW_B$.

### 3.3.1 The entrant has an innate upstream cost advantage

We begin the analysis by assuming a very high upstream cost differential ($c_u^E = 0.1$). Increasing the assumed value for $c_u^E$ ($0.1 \le c_u^E \le 1$) does not affect the entrant's profits curve $\Pi_B^I$ and the social welfare curve $SW_B$, but it does serve to shift the entrant's profits curve $\Pi_M^I$ downwards and the social welfare curve $SW_M$ initially downwards and then upwards.

From Table 1 we deduce that when the entrant is much more efficient than the incumbent in making the upstream input ($c_u^E = 0.1$ and $c_u^E = 0.2$), the $\Pi_M^I$ curve is above the $\Pi_B^I$ curve and the $SW_M$ curve is above the $SW_B$ curve for $0 < w < 1.5$.[8,9] Therefore, regardless of the input prices, the entrant's decision to make the upstream input is socially optimal when the entrant is much more efficient than the incumbent in making the upstream input. The implication is that the entrant's efficient make-or-buy decision is socially optimal.

It should be noted that as the entrant becomes less efficient in making the upstream input (but it is still more efficient than the incumbent), the incumbent's profits increase, the entrant's profits decrease and consumer surplus decrease. Hence, it is obvious that increasing $c_u^E$ makes the $\Pi_M^I$ curve shift downwards and hence intersects the $\Pi_B^I$ curve at a higher input price level. This implies that as the entrant becomes less efficient, it chooses to buy the upstream input from the incumbent for a larger range of input prices. Concerning the impact of an increase in $c_u^E$ on social welfare, we find that $SW_M$ decreases with an increase in $c_u^E$ as far as $c_u^E < c_u^I$. However, the $SW_M$ curve intersects the $SW_B$ curve at a $w \in (0,1.5)$ only for low enough upstream cost differential ($c_u^E > 0.3$). In these cases, $w^{**} > w_e$.[10] This implies that the society prefers the entrant to buy the upstream input from the incumbent for a larger range of input prices than the range that induces the entrant to buy the upstream input. Or, in other words, the society prefers the entrant to make the upstream input from the incumbent for a lower range of input prices than the range that induces the entrant to make the upstream input itself. Therefore, the entrant's efficient make-or-buy decision is not socially optimal for $w \in [w_e, w^{**})$ and is socially optimal for $w > w^{**}$.

### 3.3.2 Neither provider has an innate upstream cost advantage

Not surprisingly, when neither provider has an innate upstream cost advantage ($c_u^I = c_u^E = 0.55$), both the society and the entrant are indifferent between the latter's decision to make-or-buy the upstream input for the same input price ($w^{**} = w_e$).[11] This implies that when $w < w_e$ (respectively, $w > w_e$), the entrant chooses to buy (respectively, make) the upstream input. By combining this result with proposition 8, we deduce that when $c_u^I = c_u^E$, the make-or-buy decision undertaken by the entrant is socially optimal.

[8] See Appendix B for the proof of this inequality.

[9] See, indicatively, figures 4 and 5 in the Appendix B.

[10] See Table 1 and, indicatively, figures 6 and 7 in the Appendix B.

[11] See Table 1 and figures 8 and 9 in the Appendix B.

### 3.3.3 The incumbent has an innate upstream cost advantage

A further increase in $c_u^E$ makes the incumbent has an upstream cost advantage. As the incumbent becomes more efficient than the entrant in producing the upstream input (or as $c_u^E$ further increases), the incumbent's profits increase, the entrant's profits decrease and consumer surplus decrease. This implies that the $\Pi_M^I$ curve intersects the $\Pi_B^I$ curve at a higher input price level. Therefore, the higher the $c_u^E$, the higher the range of input prices that induces the entrant to buy the upstream input from the incumbent.

Concerning the impact of an increase in $c_u^E$ on social welfare, we find that $SW_M$ decreases with an increase in $c_u^E$ as far as $c_u^E < (c_u^E)^*$. Therefore, the $SW_M$ curve intersects the $SW_B$ curve at a higher input price. However, if $c_u^E > (c_u^E)^*$, a further increase in $c_u^E$ causes $SW_M$ to increase. Therefore, the $SW_M$ curve intersects the $SW_B$ curve at a lower input price. This implies that if the incumbent is much more efficient than the entrant in producing the upstream input, the society prefers the entrant to make the input for a very large range of input prices even though this is not an efficient outcome.

It is worth noting that regardless of the impact of an increase in $c_u^E$ on social welfare, the input price that makes the society be indifferent about the entrant's make-or-buy decision is always lower than the respective level of input price that makes the entrant be indifferent between making or buying the upstream input, that is $w^{**} < w_e$.[12] This implies that the society prefers the entrant to buy the upstream input from the incumbent for a lower range of input prices than the range that induces the entrant to buy the upstream input. Therefore, the entrant's efficient make-or-buy decision is not socially optimal for $w \in (w^{**}, w_e]$ and is socially optimal for $w < w^{**}$.

### 3.3.4 Discussion

The main conclusion concerning the analysis of the social optimality of make-or-buy decisions in the case of the Bertrand model can be stated in the following proposition:

**Proposition 9.** *In the equilibrium of the Bertrand vertical differentiation model, the efficient make-or-buy decision undertaken by the entrant is not necessarily socially optimal.*

Proposition 9 shows that unlike the cases of Hotelling and Cournot models, in which the efficient make-or-buy decision undertaken by the entrant is always socially optimal, in the Bertrand vertical differentiation model the entrant's efficient make-or-buy decision is not necessarily socially optimal. In particular, there is a set of input prices that induce the entrant to undertake its efficient make-or-buy decision which leads to lower social welfare level than the respective level resulted by not undertaking the efficient make-or-buy decision.

[12] See Table 1 and, indicatively, figures 10 and 11 in the Appendix B.

## 4. Conclusions

The aim of this paper was to study the impact of input prices on an entrant's efficient make-or-buy decision from a social perspective. Thus, it improved the results of Sappington (2005) and Gayle and Weisman (2007a), which study the impact of input prices on an entrant's efficient make-or-buy decision, by examining their impact on the subsequent level of social welfare. Some very instructive results for regulatory purposes were drawn.

First, this paper showed that when the downstream competition is described by the Hotelling model, input prices do not affect the maximization of social welfare. In addition, combining this result with those of Sappington leads us to conclude that the entrant's make-or-buy decision is not only socially optimal, but also leads to the most efficient outcome. Therefore, the absence of access regulation always leads to both efficient and socially optimal outcome. However, the inability of regulator to affect the exogenous factors, such as the providers' unit costs of producing the upstream input, may distort the fulfillment of the regulator's two-fold goal of promoting competition and encouraging investments in access infrastructures.

Second, it found that when the two providers compete á la Cournot, input prices are not necessarily irrelevant for the society's preference for the entrant's decision to make or buy the upstream input. The combination of this result with those of Gayle and Weisman showed that the entrant's make-or-buy decision is not necessarily socially optimal. However, the entrant's efficient make-or-buy decision always results in the socially optimal outcome. In particular, when the entrant has an innate upstream cost advantage, the regulator can set such an input price that leads the entrant to make the upstream input. This policy leads to (a) the most efficient outcome; (b) the socially optimal outcome; and (c) the fulfillment of regulator's two-fold goal. However, when the incumbent has an innate upstream cost advantage, the entrant's efficient make-or-buy decision only promotes service-based competition. In this case, the regulator's two-fold goal can only be fulfilled when the upstream cost differential is low enough and, of course, at the cost of efficiency distortion.

Last, in the case of the Bertrand vertical differentiation model, the impact of input prices on the society's preference for the entrant's make-or-buy decision and on the social optimality of make-or-buy decisions is as described in the case of the Cournot model. However, in the case of Bertrand model, the entrant's efficient make-or-buy decision does not always result in the socially optimal outcome. The rationale of these results is that if the entrant is much more efficient than the incumbent in producing the upstream input, the absence of access regulation leads the entrant to make the upstream input which not only results in the most efficient and socially optimal outcome, but also fulfills the regulator's two-fold goal. However, if the entrant is not much more efficient than the incumbent or the incumbent has an innate upstream cost advantage, the regulator's intervention is necessary in order to set such an input price which induces the entrant to undertake the efficient make-or-buy decision that is also socially optimal.

The above analysis showed that the particular model that describes the competition in the downstream market, as well as, each provider's efficiency in producing the upstream input have a significant impact on the social optimality of the entrant's (efficient) make-or-buy decisions. This implies that regulators should have perfect information about each provider's unit cost of producing the upstream input and the way that the two providers compete in the downstream market in order to draw their optimal access pricing policy. This paper assessed the impact of input prices on the entrant's make-or-buy decisions and on the subsequent social welfare level for every upstream cost differential for three alterative models of downstream competition. Thus, this paper provided the optimal access pricing policy that results in the best feasible outcome in terms of social welfare, productive efficiency, competition level and investment level given the upstream cost differential and the particular model of downstream competition employed.

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## Appendix A

### A1. Hotelling model

**Case 1:** *The entrant chooses to make (M) the upstream input itself*

Let $\hat{L}$ Є [0,1] denote the location of the consumer that is indifferent between purchasing from the incumbent and the entrant. Therefore, $\hat{L} = Q_M^I$. The analysis is similar to Sappington (2005) with one exception that $c_d^I = c_d^E = 0$. As a result, see Sappington (2005) for equations that give the equilibrium prices (*P*), output levels (*Q*) and profits (*Π*), for $i, j = I, E$, $i \neq j$, where prices, outputs and profits for the incumbent and the entrant are denoted by the superscript *I* and *E*, respectively.

$$P_M^i = t + \frac{2c_u^i + c_u^j}{3} \tag{A1}$$

$$Q_M^i = N[\frac{1}{2}(1 + \frac{c_u^j - c_u^i}{3t})] \tag{A2}$$

$$\Pi_M^i = N[\frac{(3t - c_u^i + c_u^j)^2}{18t}] \tag{A3}$$

Consumer surplus is given by:

$$CS_M = N\{\int_o^{\hat{L}} [v - P_M^I - t(L-0)]dL + \int_{\hat{L}}^1 [v - P_M^E - t(1-L)]dL\} \Rightarrow \tag{A4}$$

$$CS_M = N[v + (P_M^E - P_M^I)Q_M^I - P_M^E - \frac{t}{2} + tQ_M^I - t(Q_M^I)^2] \tag{A5}$$

Substituting (A1) and (A2) into (A5) provides the resulting level of consumer surplus:

$$CS_{\mathrm{M}} = N[36vt + (c_u^I)^2 - 2(c_u^I)(c_u^{\mathrm{E}}) - 18(c_u^I)t + (c_u^E)^2 - 18(c_u^E)t - 45t^2]/(36t) \tag{A6}$$

Social welfare is the sum of both providers' profits and consumer surplus:

$$SW_M = N[36vt + 5(c_u^I)^2 - 10(c_u^I)(c_u^{\mathrm{E}}) - 18(c_u^I)t + 5(c_u^E)^2 - 18(c_u^E)t - 9t^2]/(36t) \tag{A7}$$

**Case 2:** *The entrant chooses to buy (B) the upstream input from the incumbent*

Equilibrium prices, output levels and profits for the incumbent (*I*) and the entrant (*E*) are as described in Equations (A8)-(A11), for $i, j = I, E,\ i \neq j$ :

$$P_B^i = w + t \tag{A8}$$

$$Q_{\mathrm{B}}^i = N\frac{1}{2} \tag{A9}$$

$$\Pi_B^I = N(\frac{t}{2} + w - c_u^I) \tag{A10}$$

$$\Pi_B^E = N\frac{t}{2} \tag{A11}$$

For the proof of Equations (A8)-(A11) see Sappington (2005). In addition, the consumer surplus level obtained when the entrant chooses to buy the upstream input from the incumbent is given by substituting (A8) and (A9) into (A5). Therefore:

$$CS_B = N(v - w - 5t/4) \tag{A12}$$

Social welfare is the sum of both providers' profits and consumer surplus:

$$SW_B = N(v - c_u^I - t/4) \tag{A13}$$

*Proof of Proposition 1*

The result of proposition 1 is derived by comparing equations (A3) and (A11). See Sappington (2005) for the whole proof.

*Proof of Proposition 2*

From equations (A7) and (A13):

$$SW_M >=< SW_B \Leftrightarrow \tag{A14}$$

$$\begin{gathered} N[36vt + 5(c_u^I)^2 - 10(c_u^I)(c_u^{\mathrm{E}}) - 18(c_u^I)t + 5(c_u^E)^2 - 18(c_u^E)t - 9t^2]/(36t) >=< \\ N(v - c_u^I - t/4) \Leftrightarrow \end{gathered} \tag{A15}$$

$$\frac{(c_u^{\mathrm{E}} - c_u^I)}{2}[\frac{5(c_u^{\mathrm{E}} - c_u^I)}{18t} - 1] >=< 0 \tag{A16}$$

Like Sappington (2005), we assume that both the incumbent and the entrant serve retail consumers in equilibrium. Hence, $\left|c_u^j - c_u^i\right| < 3t$ (*for* $i, j =$ *I, E,* $i \neq j$). This implies that $\frac{5(c_u^{\mathrm{E}} - c_u^I)}{18t} - 1 < 0$. Therefore, from (A16) it is deduced that: (a) if $c_u^{\mathrm{E}} = c_u^I$, then $SW_M = SW_B$; (b) if $c_u^{\mathrm{E}} > c_u^I$, then $SW_M < SW_B$; and (c) if $c_u^{\mathrm{E}} < c_u^I$, then $SW_M > SW_B$.

*Proof of Proposition 3*

Given that the entrant is understood to make the efficient make-or-buy decision if it purchases the input from the incumbent when the incumbent is the least-cost supplier ($c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$) and produces the input itself whenever it is the least-cost supplier ($c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$), proposition 3 is derived straightforward by combining propositions 1 and 2.

### A2. Cournot model

**Case 1:** *The entrant chooses to make (M) the upstream input itself*

The analysis is similar to Gayle and Weisman (2007a) with one exception that $c_d^I = c_d^E = 0$. In particular, when the entrant chooses to make the upstream input itself, the profit functions for the incumbent and the entrant are given, respectively, by:

$$\Pi_M^I = (P_M - c_u^I)Q_M^I \tag{A17}$$

$$\Pi_M^E = (P_M - c_u^E)Q_M^E \tag{A18}$$

where $P = A - B(Q_M^I + Q_M^E)$. Taking the first order conditions of (A17) and (A18) with respect to $Q_M^I$ and $Q_M^E$, respectively, and solving simultaneously yields the Nash outputs:

$$Q_M^i = \frac{A + c_u^j - 2c_u^i}{3B} \tag{A19}$$

for $i, j =$ *I, E,* $i \neq j$. Substituting equation (A19) into the inverse demand function $P(Q) = A - BQ$ yields the equilibrium retail price:

$$P_M^i = \frac{A + c_u^i + c_u^j}{3} \tag{A20}$$

Substituting equations (A19) and (A20) into (A17) and (A18) yields each provider's profits:

$$\Pi_M^i = \frac{(A + c_u^j - 2c_u^i)^2}{9B} \tag{A21}$$

Consumer surplus is given by:

$$CS_{\mathrm{M}} = \frac{Q_M^2}{2} = \frac{(Q_M^I + Q_M^E)^2}{2} \Rightarrow \tag{A22}$$

$$CS_{\mathrm{M}}=\frac{(2A-c_u^I-c_u^E)^2}{18B} \tag{A23}$$

Social welfare is given by adding both providers' profits and consumer surplus:

$$SW_M=\frac{(A+c_u^E-2c_u^I)^2}{9B}+\frac{(A+c_u^I-2c_u^E)^2}{9B}+\frac{(2A-c_u^I-c_u^E)^2}{18B} \tag{A24}$$

**Case 2:** *The entrant chooses to buy (B) the upstream input from the incumbent*

The analysis is similar to Gayle and Weisman (2007a) with the exception that $c_d^I=c_d^E=0$. Therefore, see Gayle and Weisman (2007a) for equations (A25) to (A29) that provide the equilibrium retail prices (for $i, j=I, E,\ i\neq j$), each provider's output and each provider's profits when the entrant chooses to buy the upstream input itself.

$$P_B^i=\frac{A+w+c_u^I}{3} \tag{A25}$$

$$Q_{\mathrm{B}}^I=\frac{A+w-2c_u^I}{3B} \tag{A26}$$

$$Q_{\mathrm{B}}^E=\frac{A-2w+c_u^I}{3B} \tag{A27}$$

$$\Pi_B^I=\frac{(A+w-2c_u^I)^2}{9B}+\frac{(w-c_u^I)(A-2w+c_u^I)}{3B} \tag{A28}$$

$$\Pi_B^E=\frac{(A-2w+c_u^I)^2}{9B} \tag{A29}$$

Consumer surplus is given by:

$$CS_B=\frac{Q_B^2}{2}=\frac{(Q_B^I+Q_B^E)^2}{2}\Rightarrow \tag{A30}$$

$$CS_B=\frac{(2A-c_u^I-w)^2}{18B} \tag{A31}$$

Social welfare is given by adding both providers' profits and consumer surplus:

$$SW_B=\frac{(A+w-2c_u^I)^2}{9B}+\frac{(A+c_u^I-2w)^2}{9B}+\frac{(2A-c_u^I-w)^2}{18B}+\frac{(w-c_u^I)(A-2w+c_u^I)}{3B} \tag{A32}$$

*Proof of Proposition 4*

The result of proposition 4 is derived by comparing equations (A21) and (A29). See Gayle and Weisman (2007a) for the whole proof.

*Proof of Proposition 5*

From equations (A24) and (A32):

$$SW_M >=< SW_B \Leftrightarrow \tag{A33}$$

$$\frac{(A+c_u^E-2c_u^I)^2}{9B}+\frac{(A+c_u^I-2c_u^E)^2}{9B}+\frac{(2A-c_u^I-c_u^E)^2}{18B} >=< \frac{(A+w-2c_u^I)^2}{9B}+\frac{(A+c_u^I-2w)^2}{9B}+\frac{(2A-c_u^I-w)^2}{18B}+\frac{(w-c_u^I)(A-2w+c_u^I)}{3B} \Rightarrow \tag{A34}$$

$$6(c_u^I)^2-14(c_u^I)(c_u^E)-4(c_u^I)w+6A(c_u^I)+11(c_u^E)^2-8A(c_u^E)+w^2+2Aw >=< 0 \Rightarrow \tag{A35}$$

$$w >=< -A+2(c_u^I) \pm \sqrt{A^2+14(c_u^I)(c_u^E)-11(c_u^E)^2+8A(c_u^E)-10A(c_u^I)-2(c_u^I)^2} \tag{A36}$$

From (A36) we conclude that the society is indifferent about the entrant's make-or-buy decisions when $w^* = -A+2(c_u^I) \pm \sqrt{A^2+14(c_u^I)(c_u^E)-11(c_u^E)^2+8A(c_u^E)-10A(c_u^I)-2(c_u^I)^2}$. It is worth noting that we reject the second solution since it results in negative access prices. Therefore, (a) if $w = w^*$, then $SW_M = SW_B$; (b) if $w > w^*$, then $SW_M > SW_B$; and (c) if $w < w^*$, then $SW_M < SW_B$.

*Proof of Assumption 1*

(a) The first constraint is derived straightforward by (A36).

(b) When the entrant buys the upstream input from the incumbent, an increase in the access price causes the new entrant's output to decrease. Therefore, in order to ensure that the new entrant is active in the market, we assume that $Q_{\mathrm{B}}^E \geq 0$ or $w \leq \overline{w} = (A+c_u^I)/2$.

(c) When the entrant buys the upstream input from the incumbent, a decrease in the access price causes the incumbent's profits to decrease. Therefore, in order to ensure that the incumbent's profits are non-negative, we assume that $\Pi_{\mathrm{B}}^{\mathrm{I}} \geq 0$ or

$$\frac{(A+w-2c_u^I)^2}{9B}+\frac{(w-c_u^I)(A-2w+c_u^I)}{3B} \geq 0 \Rightarrow \tag{A37}$$

$$-5w^2+5w(A+c_u^I)+[A^2-7Ac_u^I+(c_u^I)^2] \geq 0 \Rightarrow \tag{A38}$$

$$[-5(A+c_u^I)+3\sqrt{5}(A-c_u^I)]/(-10) \leq w \leq [-5(A+c_u^I)-3\sqrt{5}(A-c_u^I)]/(-10) \tag{A39}$$

Therefore, the lower limit of the input prices is $\underline{w} = [-5(A+c_u^I)+3\sqrt{5}(A-c_u^I)]/(-10)$. Concerning the upper limit of the input prices, we state that the upper limit is $\overline{w} = (A+c_u^I)/2$ if and only if

$$(A+c_u^I)/2 < [-5(A+c_u^I)-3\sqrt{5}(A-c_u^I)]/(-10) \Leftrightarrow \tag{A40}$$

$$0 > -6\sqrt{5}(A-c_u^I) \tag{A41}$$

Therefore, is it obvious that (A41) holds and therefore the upper limit is $\overline{w} = (A+c_u^I)/2$.

*Proof of Lemma 1*

First, note that $\underline{w} < c_u^I < \overline{w}$. The reason is that

$$[-5(A+c_u^I)+3\sqrt{5}(A-c_u^I)]/(-10) < c_u^I \Rightarrow \tag{A42}$$

$$-5(A+c_u^I)+6,7(A-c_u^I)] > -10c_u^I \Rightarrow \tag{A43}$$

$$1,7(A-c_u^I) > 0 \tag{A44}$$

and $c_u^I < (A+c_u^I)/2 \Rightarrow 0 < A-c_u^I$ which both holds.

Furthermore, in this case, we assume that $c_u^I = c_u^E$. Therefore, substituting $c_u^I = c_u^E$ into (A36) yields:

$$SW_M >=< SW_B \Leftrightarrow \tag{A45}$$

$$w >=< -A+2(c_u^I)+\sqrt{(A-c_u^I)^2} = c_u^I \tag{A46}$$

Therefore, $w^* = -A+2(c_u^I)+\sqrt{(A-c_u^I)^2} = c_u^I$. Then Lemma 1 is straightforward.

*Proof of Lemma 2*

In this case, we assume that $c_u^E < c_u^I$. In addition $c_u^E$ cannot be lower than $\underline{w}$ because if $c_u^E < \underline{w}$ then the first constraint of assumption 1 is violated. Therefore, $\underline{w} < c_u^E < c_u^I$. However, the value of $c_u^E$ affects the relative value of $w^*$ with respect to $\underline{w}$. For this reason, we calculate the values of $c_u^E$ that causes $w^* = \underline{w}$. Hence,

$$\begin{aligned}&-A+2(c_u^I)+\sqrt{A^2+14(c_u^I)(c_u^E)-11(c_u^E)^2+8A(c_u^E)-10A(c_u^I)-2(c_u^I)^2} = \\ &-5(A+c_u^I)+3\sqrt{5}(A-c_u^I)]/(-10)\end{aligned} \tag{A47}$$

The solution of (A47) shows that $w^* = \underline{w}$ if

$$c_u^E = \frac{4A+7c_u^I}{11} \pm (A \mp c_u^I)\sqrt{\frac{198\sqrt{5}-54}{5}} \tag{A48}$$

The first solution of (A48) is rejected because it causes $c_u^E > c_u^I$. Therefore, the critical value of $c_u^E$ that causes $w^* = \underline{w}$ is $(c_u^E)' = \frac{4A+7c_u^I}{11} - (A+c_u^I)\sqrt{\frac{198\sqrt{5}-54}{5}}$. It follows that $(c_u^E)' < c_u^I$.

As a result if $c_u^E < (c_u^E)' < c_u^I$ then $w^* < \underline{w}$ and if $(c_u^E)' < c_u^E < c_u^I$ then $w^* > \underline{w}$. However, we should also prove that $w^* < c_u^E$ when $c_u^E < c_u^I$. Indeed,

$$w^* < c_u^E \Rightarrow \tag{A49}$$

$$-A+2(c_u^I)+\sqrt{A^2+14(c_u^I)(c_u^E)-11(c_u^E)^2+8A(c_u^E)-10A(c_u^I)-2(c_u^I)^2} < c_u^E \Rightarrow \tag{A50}$$

$$A^2+14(c_u^I)(c_u^E)-11(c_u^E)^2+8A(c_u^E)-10A(c_u^I)-2(c_u^I)^2 < (A+c_u^E-2c_u^I)^2 \Rightarrow \tag{A51}$$

$$A(c_u^E-c_u^I)-2c_u^E(c_u^E-c_u^I)+c_u^I(c_u^E-c_u^I) < 0 \Rightarrow \tag{A52}$$

$$(c_u^E - c_u^I)(A - 2c_u^E + c_u^I) < 0 \tag{A53}$$

which holds since $c_u^E < c_u^I$ and $A - 2c_u^E + c_u^I > 0$ because $Q_B^E > 0$. Note that if $c_u^E = c_u^I$ then $w^* = c_u^E = c_u^I$ (as we have already proven) and if $A - 2c_u^E + c_u^I = 0 \Rightarrow c_u^E = (A + c_u^I)/2$, then $w^* = c_u^E$, as well. However, since we assume that $c_u^E < c_u^I$, the only feasible solution is $w^* < c_u^E$. This completes the proof of lemma 2.

*Proof of Lemma 3*

In this case, we assume that $c_u^E > c_u^I$. Therefore, from (A53) we deduce that $w^* > c_u^E$ if $c_u^I < c_u^E < (A + c_u^I)/2$ and $w^* = c_u^E$ if $c_u^E = \overline{w} = (A + c_u^I)/2$. As a result, we have examined the relative value of $w^*$ with respect to $c_u^E$. In addition, we should examine the relative value of $w^*$ with respect to $\overline{w}$. For this reason, we calculate the values of $c_u^E$ that causes $w^* = \overline{w}$. Hence,

$$-A + 2(c_u^I) + \sqrt{A^2 + 14(c_u^I)(c_u^E) - 11(c_u^E)^2 + 8A(c_u^E) - 10A(c_u^I) - 2(c_u^I)^2} = (A + c_u^I)/2 \tag{A54}$$

The solution of (A54) shows that $w^* = \overline{w}$ if

$$c_u^E = (c_u^E)'' = \frac{5A + 17c_u^I}{22} \tag{A55}$$

or

$$c_u^E = (A + c_u^I)/2 \tag{A56}$$

Therefore, we conclude that (a) if $c_u^E = (A + c_u^I)/2$ then $c_u^E = w^* = \overline{w}$; (b) if $c_u^E < (c_u^E)''$ then $w^* < \overline{w}$; and (c) if $c_u^E > (c_u^E)''$ then $w^* > \overline{w}$. Moreover, if $c_u^E = (c_u^E)''$ then $w^* = \overline{w}$. Last, from equation (A55) it is obvious that $c_u^I < (c_u^E)''$ since $A > c_u^I$. This completes the proof of lemma 3.

*Proof of Proposition 6*

Firstly, let $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$. Given that (a) the entrant is understood to make the efficient make-or-buy decision if it purchases the input from the incumbent when the incumbent is the least-cost supplier ($c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$); and (b) the implication of proposition 4 that the entrant buys the input from the incumbent when $w < c_u^{\mathrm{E}}$, we conclude that the entrant undertakes the efficient make-or-buy decision when $w < c_u^{\mathrm{E}}$. In addition, given the result of lemma 3 that $c_u^E < w^*$ and the implication of proposition 5 that the entrant's decision to buy the upstream input from the incumbent is socially optimal when $w < w^*$, it follows that $w < c_u^{\mathrm{E}}$ is a necessary and sufficient condition to ensure that the entrant's efficient decision to buy the upstream input is also socially optimal.

Secondly, let $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$. Given that (a) the entrant is understood to make the efficient make-or-buy decision if it makes the input when it is the least-cost supplier ($c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$); and (b) the implication of proposition 4 that the entrant makes the input when $w > c_u^{\mathrm{E}}$, we conclude that the entrant undertakes the efficient make-or-buy decision when $w > c_u^{\mathrm{E}}$. In addition, given the result of lemma 2 that $c_u^E > w^*$ and the implication of proposition 5 that the entrant's decision to make the upstream input is socially optimal when $w > w^*$, it follows that $w > c_u^{\mathrm{E}}$ is a necessary and sufficient condition to ensure that the entrant's efficient decision to make the upstream input is also socially optimal.

By combining the above results, it can be concluded that the entrant's efficient make-or-buy decision is always socially optimal in the equilibrium of the Cournot model.

### A3. Bertrand vertical differentiation model

The analysis is similar to Gayle and Weisman (2007a) with one exception that $c_d^I = c_d^E = 0$. Therefore, the consumer whose taste parameter is $\tilde{\theta} = P^l / \lambda_l$ is indifferent between buying and not buying, whereas the consumer whose taste parameter is $\hat{\theta} = (P^h - P^l)/(\lambda_h - \lambda_l)$ is indifferent between the high and the low quality product. As a result, the demand functions for the incumbent and the entrant are given, respectively, by:

$$Q^l = \frac{P^h}{\lambda_h - \lambda_l} - \frac{\lambda_h P^l}{\lambda_l(\lambda_h - \lambda_l)} \tag{A57}$$

$$Q^h = 1 - \frac{P^h - P^l}{\lambda_h - \lambda_l} \tag{A58}$$

**Case 1:** *The entrant chooses to make (M) the upstream input itself*

The profit functions for the incumbent and the entrant are given, respectively, by:

$$\Pi_M^h = (P^h - c_u^I)Q^h \tag{A59}$$

$$\Pi_M^l = (P^l - c_u^E)Q^l \tag{A60}$$

See Gayle and Weisman (2007a) for equations (A61), (A62), (A63) and (A64) that provide the equilibrium retail prices, the entrant's output and the entrant's profits when the entrant chooses to make the upstream input itself.

$$P_M^h = \frac{\lambda_h[2(\lambda_h - \lambda_l) + 2c_u^I + c_u^E]}{4\lambda_h - \lambda_l} \tag{A61}$$

$$P_M^l = \frac{\lambda_l(\lambda_h - \lambda_l) + \lambda_l c_u^I + 2\lambda_h c_u^E]}{4\lambda_h - \lambda_l} \tag{A62}$$

$$Q_M^l = \frac{\lambda_h[\lambda_l(\lambda_h - \lambda_l) + \lambda_l c_u^I + \lambda_l c_u^E - 2\lambda_h c_u^E]}{\lambda_l(4\lambda_h - \lambda_l)(\lambda_h - \lambda_l)} \tag{A63}$$

$$\Pi_M^l = \frac{\lambda_h[\lambda_l(\lambda_h - \lambda_l) + \lambda_l c_u^I + \lambda_l c_u^E - 2\lambda_h c_u^E]^2}{\lambda_l(\lambda_h - \lambda_l)(4\lambda_h - \lambda_l)^2} \tag{A64}$$

Substituting equations (A61) and (A62) into (A58) and rearranging yields the incumbent's output.

$$Q_M^h = \frac{2\lambda_h(\lambda_h-\lambda_l)+c_u^I(2\lambda_h-\lambda_l)+\lambda_l c_u^E}{(4\lambda_h-\lambda_l)(\lambda_h-\lambda_l)} \tag{A65}$$

In addition, substituting the resulting incumbent's output $Q_M^h$ and (A61) into (A59) gives the incumbent's profits:

$$\Pi_M^h = \frac{[2\lambda_h(\lambda_h-\lambda_l)+c_u^I(2\lambda_h-\lambda_l)+\lambda_l c_u^E]^2}{(\lambda_h-\lambda_l)(4\lambda_h-\lambda_l)^2} \tag{A66}$$

Consumer surplus is given by:

$$CS = \int_{\tilde{\theta}}^{\hat{\theta}}(\theta\lambda_l - P^l)d\theta + \int_{\hat{\theta}}^{1}(\theta\lambda_h - P^h)d\theta \Rightarrow \tag{A67}$$

$$CS = \frac{\lambda_l}{2}(\hat{\theta}^2-\tilde{\theta}^2) - P^lQ^l + \frac{\lambda_h}{2}(1-\hat{\theta}^2) - P^hQ^h \tag{A68}$$

Substituting the equilibrium prices and quantities and the resulting values of $\hat{\theta}$ and $\tilde{\theta}$ into (A68) provides the consumer surplus level when the entrant chooses to make the upstream input itself.

$$CS_M = \frac{\begin{array}{c}\lambda_h[4\lambda_h{}^3\lambda_l{}^2+\lambda_h{}^2\lambda_l{}^2-8\lambda_h{}^2\lambda_l c_u^E+4\lambda_h{}^2(c_u^E)^2-5\lambda_h\lambda_l{}^3+\\ 6\lambda_h\lambda_l{}^2c_u^I+8\lambda_h\lambda_l{}^2c_u^E+4\lambda_h\lambda_l(c_u^I)^2-3\lambda_h\lambda_l(c_u^E)^2]\end{array}}{2\lambda_l(\lambda_h-\lambda_l)(4\lambda_h-\lambda_l)^2} \tag{A69}$$

Social welfare is the sum of both providers' profits and consumer surplus, that is:

$$SW_M = \Pi_M^h + \Pi_M^l + CS_M \tag{A70}$$

**Case 2:** *The entrant chooses to buy (B) the upstream input from the incumbent*

The profit functions for the incumbent and the entrant are given, respectively, by:

$$\Pi_B^h = (P^h - c_u^I)Q^h + (w - c_u^I)Q^l \tag{A71}$$

$$\Pi_B^l = (P^l - w)Q^l \tag{A72}$$

See Gayle and Weisman (2007a) for equations (A73), (A74), (A75) and (A76) that provide the equilibrium retail prices, the entrant's output and the entrant's profits when the entrant chooses to buy the upstream input from the incumbent.

$$P_B^h = \frac{\lambda_h[2(\lambda_h-\lambda_l)+3w]}{4\lambda_h-\lambda_l} \tag{A73}$$

$$P_B^l = \frac{\lambda_l(\lambda_h-\lambda_l)+w(2\lambda_h+\lambda_l)]}{4\lambda_h-\lambda_l} \tag{A74}$$

$$Q_B^l = \frac{\lambda_h(\lambda_l-2w)}{\lambda_l(4\lambda_h-\lambda_l)} \tag{A75}$$

$$\Pi_B^l = \frac{\lambda_h(\lambda_h-\lambda_l)(\lambda_l-2w)^2}{\lambda_l(4\lambda_h-\lambda_l)^2} \qquad \text{(A76)}$$

Substituting equations (A73) and (A74) into (A58) and rearranging yields the incumbent's output:

$$Q_B^h = \frac{2\lambda_h - w}{4\lambda_h - \lambda_l} \qquad \text{(A77)}$$

In addition, substituting the resulting incumbent's output $Q_B^h$ and equations (A73) and (A75) into (A71) gives the incumbent's profits:

$$\Pi_B^h = \frac{\begin{array}{c}4\lambda_h^3\lambda_l - 4\lambda_h^2\lambda_l^2 + 8\lambda_h^2\lambda_l w - 12\lambda_h^2\lambda_l c_u^I - 8\lambda_h^2 w^2 + 8\lambda_h^2 c_u^I w + \\ \lambda_h\lambda_l^2 w + 3\lambda_h\lambda_l^2 c_u^I - \lambda_h\lambda_l w^2 + 2\lambda_h\lambda_l c_u^I w - \lambda_l^2 c_u^I w\end{array}}{\lambda_l(4\lambda_h-\lambda_l)^2} \qquad \text{(A78)}$$

Consumer surplus is given by (A68). Substituting the equilibrium prices and quantities and the resulting values of $\hat{\theta}$ and $\tilde{\theta}$ into (A68) provides the consumer surplus level when the entrant chooses to buy the upstream input from the incumbent.

$$CS_B = \frac{\lambda_h(4\lambda_h^2\lambda_l + 5\lambda_h\lambda_l^2 - 16\lambda_h\lambda_l w + 4\lambda_h w^2 - 2\lambda_l^2 w + 5\lambda_l w^2)}{2\lambda_l(4\lambda_h-\lambda_l)^2} \qquad \text{(A79)}$$

Social welfare is the sum of both providers' profits and consumer surplus, that is:

$$SW_B = \Pi_B^h + \Pi_B^l + CS_B \qquad \text{(A80)}$$

*Proof of Proposition 7*

The result of proposition 7 is derived by comparing equations (A64) and (A76). See Gayle and Weisman (2007a) for the whole proof.

*Proof of Proposition 8*

From equations (A70) and (A80):

$$SW_M >=< SW_B \Leftrightarrow \qquad \text{(A81)}$$

$$\frac{\begin{array}{l}(8\lambda_h^3\lambda_l c_u^E - 8\lambda_h^3\lambda_l w + 16\lambda_h^3 c_u^I w - 12\lambda_h^3(c_u^E)^2 - 4\lambda_h^3 w^2 - 4\lambda_h^2\lambda_l^2 c_u^I - \\ 12\lambda_h^2\lambda_l^2 c_u^E + 16\lambda_h^2\lambda_l^2 w + 12\lambda_h^2\lambda_l(c_u^I)^2 + 16\lambda_h^2\lambda_l c_u^I c_u^E + 12\lambda_h^2\lambda_l c_u^I w + \\ 9\lambda_h^2\lambda_l(c_u^E)^2 - \lambda_h^2\lambda_l w^2 + 4\lambda_h\lambda_l^3 c_u^I + 4\lambda_h\lambda_l^3 c_u^E - 8\lambda_h\lambda_l^3 w + 9\lambda_h\lambda_l^2(c_u^I)^2 - \\ 6\lambda_h\lambda_l^2 c_u^I c_u^E - 6\lambda_h\lambda_l^2 c_u^I w - 2\lambda_h\lambda_l^2(c_u^E)^2 + 5\lambda_h\lambda_l^2 w^2 - 2\lambda_l^3(c_u^I)^2 + 2\lambda_l^3 c_u^I w)\end{array}}{2\lambda_l(\lambda_h-\lambda_l)(4\lambda_h-\lambda_l)^2} >=< 0 \qquad \text{(A82)}$$

Solving (A82) with respect to *w* provides two values of *w* that make the society be indifferent about the entrant's decision to make or buy the upstream input. Depending on the particular values of $c_u^I$ and $c_u^E$, (a) the one optimal value of *w* is positive and the other negative; (b) both are positive; or (c) do not exist. In the numerical example provided here, it is assumed that $c_u^I$ is low enough in order to exclude the second case. Thus, let us denote the potential positive root of equation (A82) by $w^{**}$. Therefore, proposition 8 has been just proved. However, if $c_u^I$ is high enough ($c_u^I \geq 0.65$ in our example), the $SW_B$ curve initially increases with an increase in the input price, reaches its maximum level and then decreases. Therefore, for high enough $c_u^E$ ($c_u^E \geq 0.45$ in our example), there are two positive values of *w* that make the society be indifferent about the entrant's decision to make or buy the upstream input. In addition, if $c_u^E$ is low enough, $SW_M$ is greater than $SW_B$ for all admissible values of *w*.

*Proof of Proposition 9*

From Table 1 we deduce that if $c_u^E < c_u^I$ then $w_e < w^{**}$. Therefore, the entrant undertakes the efficient decision to make the upstream input itself for $w > w_e$, whereas such a decision is socially optimal only for $w > w^{**}$. Since, $w^{**} > w_e$, it can be concluded that the entrant's efficient decision to make the upstream input is not socially optimal for $w \in [w_e, w^{**})$ and is socially optimal for $w > w^{**}$. In addition, regardless of the input price, the entrant's efficient decision to make the upstream input is also socially optimal when the upstream cost differential is very high (see figures 4 and 5). On the contrary, from Table 1 we deduce that if $c_u^E > c_u^I$ then $w_e > w^{**}$. Therefore, the entrant undertakes the efficient decision to buy the upstream input from the incumbent for $w < w_e$, whereas such a decision is socially optimal only for $w < w^{**}$. It can be concluded that the entrant's efficient decision to buy the upstream input is not socially optimal for $w \in (w^{**}, w_e]$ and is socially optimal for $w < w^{**}$. Hence, the efficient make-or-buy decision undertaken by the entrant is not necessarily socially optimal.

## Appendix B

The following is a numerical example used to analyze the impact of input prices on the social optimality of an entrant's efficient make-or-buy decision when the downstream competition is described by the Bertrand vertical differentiation model. It is instructive to limit our study to the range of input prices for which both providers are active in the market. Thus, we assume that $w < \lambda_l / 2$ which ensures that $Q_B^l > 0$ and $c_u^E < \dfrac{\lambda_l(\lambda_h - \lambda_l) + \lambda_l c_u^I}{2\lambda_h - \lambda_l}$ which ensures that $Q_M^l > 0$. The assumed parameter values are $c_u^I = 0.55$, $\lambda_h = 5$ and $\lambda_l = 3$. Therefore, we find the entrant's profits and the social welfare level when the former chooses to make the upstream input itself and when it chooses to buy the upstream input from the incumbent for $0 < w < 1.5$ and $0 < c_u^E < 1.092$. This implies that we discriminate between three cases regarding the incumbent's and the entrant's unit costs of producing the upstream input:

(a) when $0 < c_u^E < 0.55$, the entrant has an innate upstream cost advantage. See, indicatively, figures 4 and 5 for the case that the upstream cost differential is high enough and figures 6 and 7 for the case that the upstream cost differential is low enough;

(b) when $c_u^E = 0.55$, neither provider has an innate upstream cost advantage. The derived results are presented in figures 8 and 9; and

(c) when $0.55 < c_u^E < 1.092$, the incumbent has an innate upstream cost advantage. See, indicatively, figures 10 and 11 for a graphical presentation of the derived results.

The following table shows the values of input prices $w^{**}$ and $w_e$ for different values of $c_u^E$ that affect the upstream cost differential.

| $c_u^E$ | $w_e$ | $w^{**}$ |
|---|---|---|
| 0.1 | - | - |
| 0.2 | - | - |
| 0.3 | 0.1125 | - |
| 0.4 | 0.2875 | 0.3023 |
| 0.5 | 0.4624 | 0.4957 |
| 0.55 | 0.55 | 0.55 |
| 0.6 | 0.6375 | 0.5881 |
| 0.7 | 0.8125 | 0.6268 |
| 0.8 | 0.9875 | 0.6219 |
| 0.9 | 1.1625 | 0.5724 |
| 1 | 1.3975 | 0.4638 |

**Table 1** The values of $w^{**}$ and $w_e$ for different upstream cost differentials

Applying the values of Table 1 to propositions 7 and 8 and combining the derived results proves proposition 9 (as proved in Appendix A3). It is worth noting that the particular values of parameters $\lambda_h$ and $\lambda_l$ do not have an impact on the social optimality of an entrant's make-or-buy decisions. The following figures present graphically the derived results of Table 1 when $c_u^E = 0.1$, $c_u^E = 0.4$, $c_u^E = 0.55$ and $c_u^E = 0.8$. Each of these four upstream cost differentials reflects an indicative example of the special cases described above and in the text.

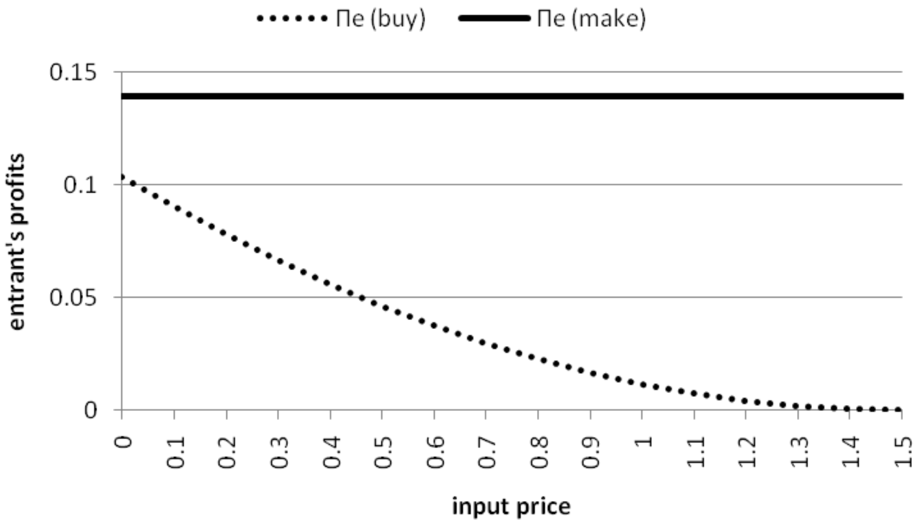


**Fig. 4** Entrant's profits as a function of *w* for $c_u^E = 0.1$

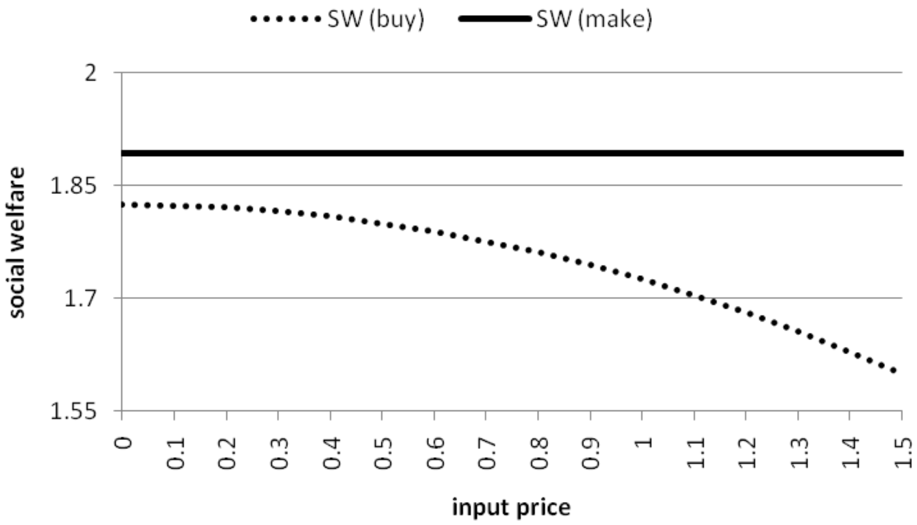


**Fig. 5** Social welfare level as a function of *w* for $c_u^E = 0.1$

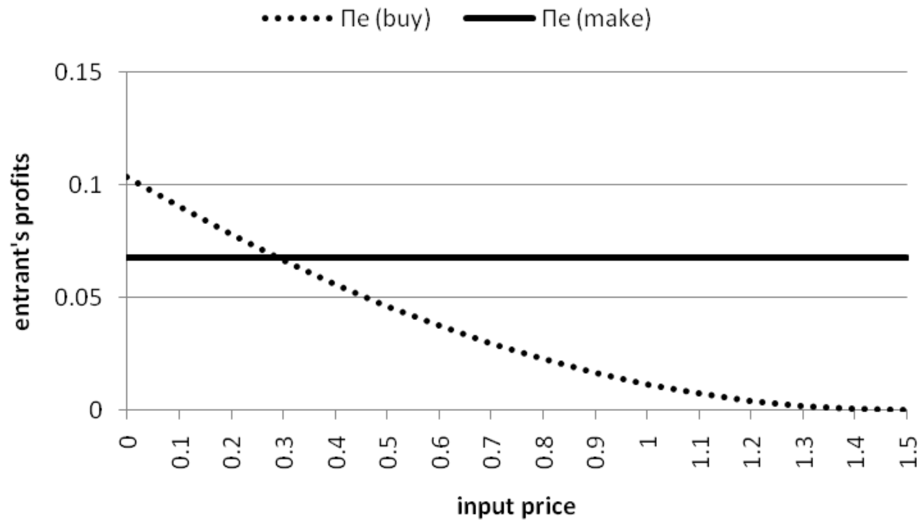


**Fig. 6** Entrant's profits as a function of *w* for $c_u^E = 0.4$

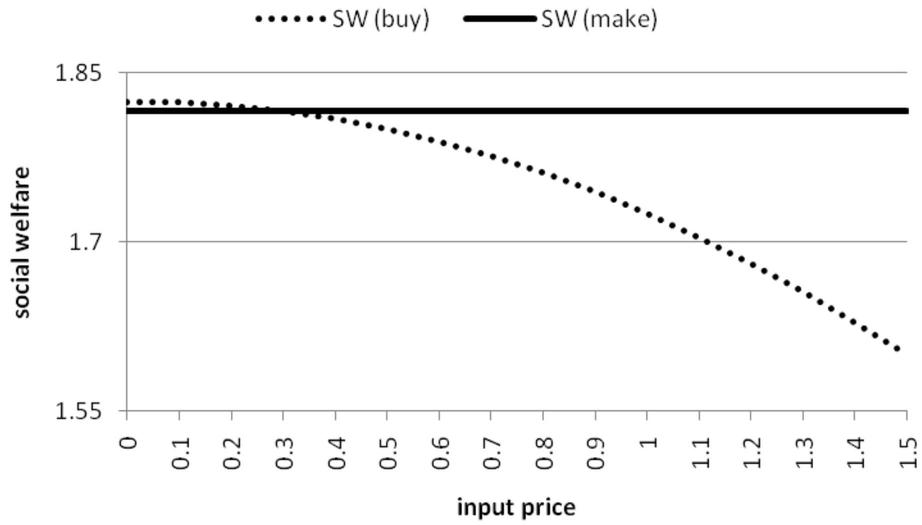


**Fig. 7** Social welfare level as a function of *w* for $c_u^E = 0.4$

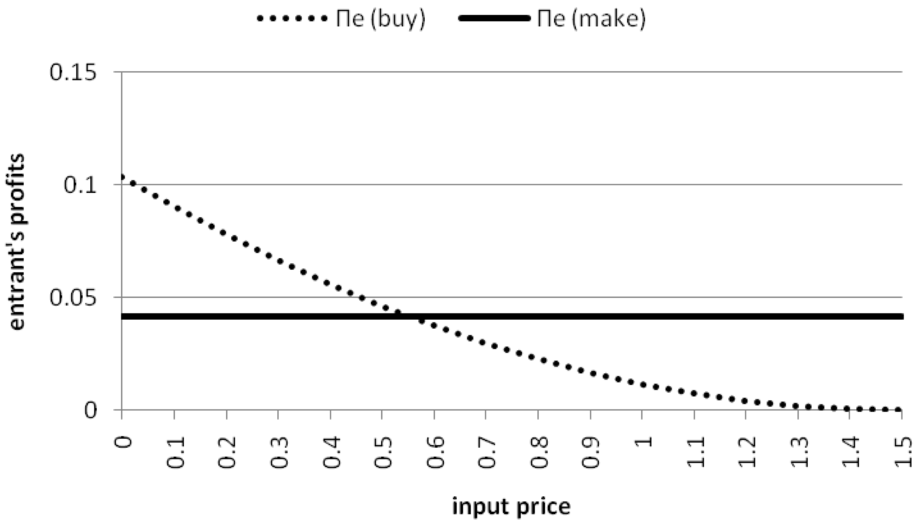


**Fig. 8** Entrant's profits as a function of *w* for $c_u^E = 0.55$

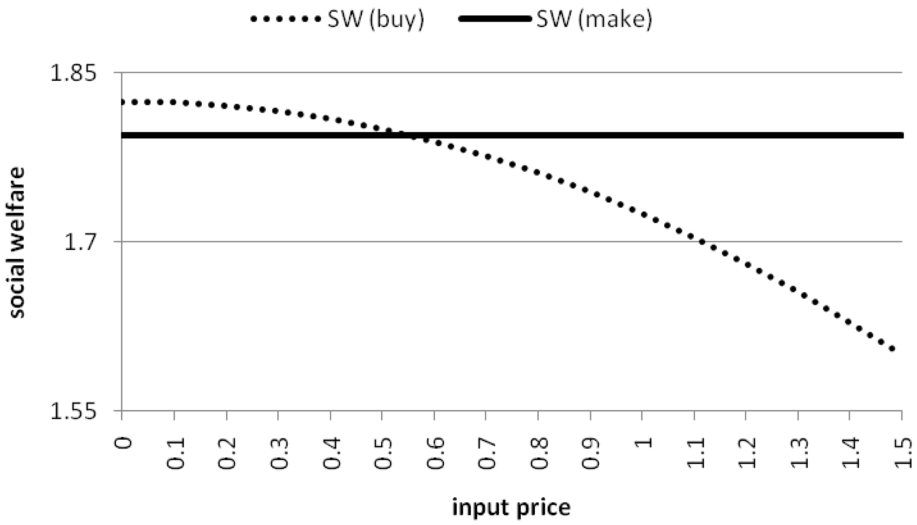


**Fig. 9** Social welfare level as a function of *w* for $c_u^E = 0.55$

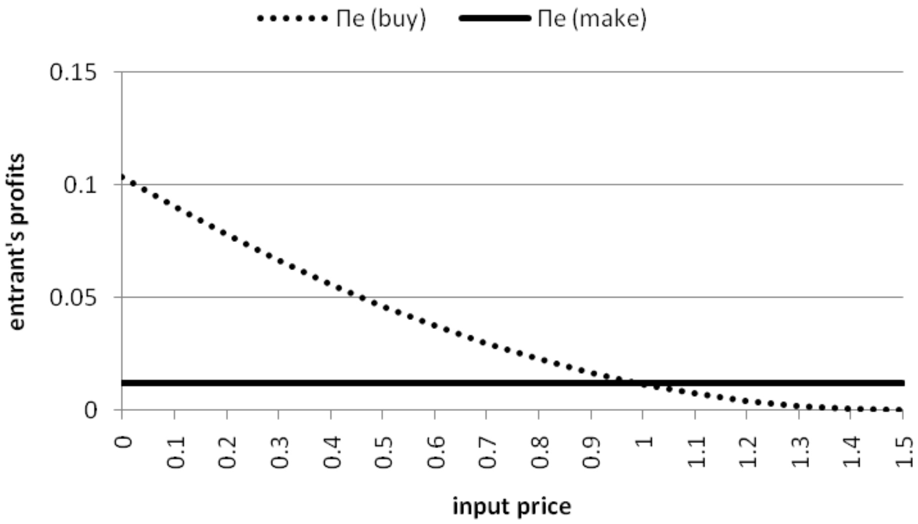


**Fig. 10** Entrant's profits as a function of *w* for $c_u^E = 0.8$

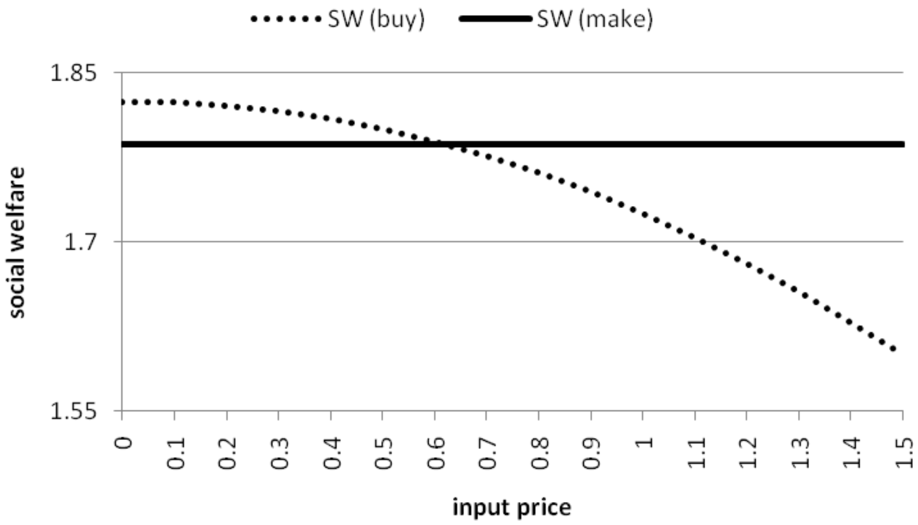


**Fig. 11** Social welfare level as a function of *w* for $c_u^E = 0.8$

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# On the irrelevance of input prices from a regulatory perspective

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ABSTRACT

The 1996 Telecommunications Act requires incumbent providers to lease network inputs to rivals at cost-based prices in order to secure lower prices and higher quality services through service-based competition. Once service-based competition has been established, the Act aims at promoting investment in alternative network infrastructures through facilities-based competition. Hence, access (input) price regulation aims at both securing service-based competition and promoting facilities-based competition. Sappington (Sappington, D. (2005). *American Economic Review*, 95(5), 1631-1638) uses the standard Hotelling model to show that input prices are irrelevant for an entrant's decision to make or buy an essential input for downstream production. Hence, he shows that input price regulation is not an efficient instrument to promote facilities-based competition. We show that input prices are also irrelevant for the maximization of social welfare and, as a result, input price regulation is also an inefficient instrument to secure service-based competition. Therefore, input prices are irrelevant from the regulatory perspective. In particular, we show that the efficient make-or-buy decision undertaken by an entrant is always socially optimal. Hence, when the entrant prefers to make the upstream input, both regulator's goals are fulfilled, whereas when the entrant prefers to buy the upstream input from the incumbent, the regulator fails to promote facilities-based competition.

## 1. Introduction

The Telecommunications Act of 1996 authorized new suppliers (entrants) of telecommunications services to have access to incumbent suppliers' key network elements at cost-based prices.[1] The purpose of this policy is "to promote competition and reduce regulation in order to secure lower prices and higher

[1] See Armstrong (2002) and Valletti and Estache (1998) for an excellent and extensive review of the literature on access pricing.

quality services for American telecommunications consumers and encourage the rapid deployment of new telecommunications technologies". Hence, the ultimate goal of this unbundling policy is twofold. First, it aims at inducing service-based competition in the downstream (retail) market which leads to lower prices, higher quality and higher social welfare. Second, once service-based competition has been established, it aims at promoting facility-based competition which leads to innovation and market growth. Service-based competition requires mandated access to the incumbent network, whereas facility-based competition requires investment in network infrastructure by incumbents and, especially, entrants.

The optimal access price that maximizes social welfare and promotes network investment is still an open issue. Existing studies on regulation and investment, mainly in broadband market, examine this issue from both theoretical and empirical perspective.[2]

Jorde, Sidak and Teece (2000) examine the impact of access price on total investment incentives. They show that regulating access prices based on TELRIC (Total Element Long-Run Incremental Cost) methodology discourages incumbents to invest and encourages entrants to deviate from socially optimal investment level and to delay entry. Ingraham and Sidak (2003) confirm empirically the result of Jorde, Sidak and Teece (2000). In addition, Friederiszick, Grajek and Roller (2008) study the correlation between unbundling and investment in 25 European countries for the period 1997-2006 and find that unbundling discourages infrastructure investment by entrants in fixed-line telecommunications but does not affect substantially the incumbent's investment in fixed-line services.

Vareda (2007) studies the effect of access price regulation on the incumbent's incentives to invest. He shows that unbundling may lower the incumbent's incentives to invest in quality upgrades but it also raises the incentives in cost-reduction investment. Hence, the aggregate effect of access price regulation on incumbent's incentives to invest is doubtful.

Another set of papers addresses and analyzes the effect of access price regulation on entrants' incentives to invest in alternative infrastructures. Crandall, Ingraham and Singer (2004) conclude that unbundling decreases facilities-based competition in the short term. However, they point out that their model cannot rule out the possibility that low UNE (unbundled network elements) rates encourage the entrants to rent at first, and then build facilities once they have some market experience. Cave and Vogelsang (2003), based on the fact that entrants will typically invest in replicable assets first and then progress to less replicable ones, suggest that at the initial stage of competition the access price for the less replicable network elements should be low but increasing over time as assets are replicated. This theory is widely known as "ladder of investment". Avenali, Matteucci and Reverberi (2008) argue for the efficiency of an access price that rises over time for fostering investment by new entrants. Using a simulation model, Christodoulou and Vlahos (2001) show that a "mix" of infrastructure and service competition with a gradually increasing price of the UNE from an initially low level to forward-looking costs stimulates investment by both incumbents and entrants.

[2] See (Cambini and Jiang, 2009) for an excellent and extensive review of the literature on broadband investment and regulation.

From the above studies we infer that, although there is a great controversy about the effect of access regulation on investment incentives, most researchers agree that an access price too low may deter investment in alternative networks and an access price too high would discourage entrants from joining service-based competition. Hence, the regulatory policy should reflect the trade-off between the short-run benefits from service-based competition and long-run benefits of improved facility-based competition.

However, Sappington (2005) shows that input prices are irrelevant for an entrant's decision to make or buy an input required for downstream production. This result is striking since it negates most of the above studies. He uses the standard Hotelling model of competition to compare the new entrant's profits when it purchases an essential upstream input from the incumbent and when it makes the upstream input itself. He concludes that "the entrant undertakes the efficient make-or-buy decision if it purchases the upstream input from the incumbent whenever the incumbent is the least-cost supplier of the input, and produces the upstream input itself whenever it is the least-cost supplier of the input". In other words, the entrant compares its cost and the incumbent's cost of making the input in order to undertake the efficient make-or-buy decision. Hence, the actual level of input prices is irrelevant. According to Sappington, the reason of this striking result is that previous studies fail to take into account the impact of a new entrant's make-or-buy decision on subsequent retail price competition. After Sappington's suggestion, Gayle and Weisman (2007) consider alternative downstream interactions and show that input prices are not necessarily irrelevant in the Bertrand vertical differentiation model and are not irrelevant in the Cournot model.

As we have already mentioned above, the regulator aims at setting the access price that not only maximizes social welfare but also induces investment in alternative networks. Sappington (2005) studies the effect of input prices on the entrant's incentives to make the upstream input. In this paper, we complement Sappington's result by studying the effect of input prices on social welfare. Like Sappington, we use the standard Hotelling model and show that input prices are irrelevant for the regulator's goal to maximize social welfare. In particular, we show that when the incumbent (entrant) is the least-cost supplier of the input, social welfare is maximized when the entrant decides to buy (make) the input. Therefore, the efficient make-or-buy decision undertaken by the entrant maximizes social welfare.[3]

This indifference result is also striking because it proves that input prices affect neither service-based nor facilities-based competition.[4] In addition, we show that the efficient make-or-buy decision undertaken by the entrant is always socially optimal. Therefore, although it seems that access price regulation is an inefficient instrument of fulfilling the regulator's twofold goal, it always succeeds in maximizing social welfare.

The rest of the paper is organized as follows. Section 2 gives an outline of the basic assumptions and definitions of our model. Section 3 presents the main

[3] Shim and Oh (2006) also state that the level of the input price does not affect the entrant's profits and the total social surplus. However, they do not combine this result with the entrant's efficient make-or-buy decision.

[4] It should be noted that the irrelevance of input prices on social welfare is sensitive to the particular model of competition employed.

findings of this paper. The last section summarizes the key findings and makes regulatory implications.

## 2. Assumptions and definitions

We consider a duopoly case where there are two suppliers whose final services are differentiated á la Hotelling (1929). The two rivals are located at the two extremities of the market. The incumbent is located at point $L_i = 0$ and the entrant is located at point $L_e = 1$. *N* consumers are uniformly distributed on the unit interval [0,1]. Consumers are endowed with utility $U_L(L_j, P_j) = v - P_j - t(L_j - L\ )$. Consumer utility $U_L$ has a peak where the consumer's location *L* and the firm's location coincide. The term $t(L_j - L\ )$ can be interpreted as the linear transportation (disutility) cost which the consumer located at point *L* Є [0,1] incurs through the distance of transport. $v > 0$ can be interpreted as the reservation price and it is assumed that it exceeds the sum of price and transport cost in order to assure that each consumer buys one unit of the final service. $P_j$ $(j = i, e)$ represents the price at which each provider supplies its final service.

Each unit of the downstream service requires one unit of an upstream input and one unit of the downstream input. Each firm supplies its own downstream input. The unit costs of producing the downstream input are $c_d^I$ and $c_d^{\mathrm{E}}$ for the incumbent and the entrant, respectively. The incumbent's and entrant's unit costs of producing the upstream input are denoted by $c_u^I$ and $c_u^{\mathrm{E}}$, respectively. Without loss of generality, we further assume that the unit cost of producing the downstream input is the same for the two retailers and is set to zero.

The price at which the entrant can purchase the upstream input from the incumbent is denoted by *w*. The regulator sets the input (access) price that maximizes social welfare. Then the entrant decides whether it will buy the upstream input from the incumbent or produce it itself. Once the entrant has made its efficient make-or-buy decision, the providers choose their retail prices that maximize their profits. Finally, consumers make their purchase decisions.

## 3. Findings

In this section we estimate the input price that maximizes social welfare (*SW*) defined as the unweighted sum of profits and consumer surplus. We use the backward induction method to solve this problem. Equilibrium prices (*p*), output levels (*Q*), profits (*Π*), consumer surplus (*CS*) and social welfare (*SW*) are as characterized in Lemmas 1 and 2. Prices, outputs and profits for the incumbent and the entrant are denoted by the superscript *I* and *E*, respectively. The subscript *M* (respectively, *B*) denotes prices, outputs, profits, consumer surplus and social welfare following the entrant's decision to make (respectively, buy) the upstream input.

LEMMA 1: *If the entrant chooses to produce the upstream input itself, equilibrium retail prices, outputs, profits, consumer surplus and social welfare are (for* $i, j =$ *I, E,* $i \neq j$*):*

(1) $$P_M^i = t + \frac{2c_u^i + c_u^j}{3}$$

(2) $$Q^i_M = N[\frac{1}{2}(1+\frac{c^j_u - c^i_u}{3t})]$$

(3) $$\Pi^i_M = N[\frac{(3t - c^i_u + c^j_u)^2}{18t}]$$

(4) $$CS_{\mathrm{M}} = N[v - t - \frac{c^I_u + 2c^{\mathrm{E}}_u}{3} + \frac{(c^{\mathrm{E}}_u - c^I_u)^2}{18t}]$$

(5) $$SW_M = N[v - \frac{c^I_u + 2c^{\mathrm{E}}_u}{3} + \frac{(c^{\mathrm{E}}_u - c^I_u)^2}{6t}]$$

LEMMA 2: *If the entrant chooses to buy the upstream input from the incumbent, equilibrium retail prices, outputs, profits, consumer surplus and social welfare are (for $i, j = I, E,\ i \neq j$):*

(6) $$P^i_B = w + t$$

(7) $$Q^i_{\mathrm{B}} = N\frac{1}{2}$$

(8) $$\Pi^I_B = N(\frac{t}{2} + w - c^I_u)$$

(9) $$\Pi^E_B = N\frac{t}{2}$$

(10) $$CS_B = N(v - w - t)$$

(11) $$SW_B = N(v - c^I_u)$$

Sappington (2005) discusses the entrant's efficient make-or-buy decision by comparing equations (3) and (9). His main finding is stated in proposition 1:

PROPOSITION 1 (Sappington): *Regardless of the established price (w) of the upstream input: (a) the entrant prefers to buy the upstream input from the incumbent when the incumbent is the least-cost supplier of the input (i.e.* $\Pi^E_B > \Pi^E_M$ if $c^{\mathrm{I}}_u < c^{\mathrm{E}}_u$) *and (b) the entrant prefers to make the upstream input itself when it is the least-cost supplier of the input (i.e.* $\Pi^E_{\mathrm{M}} > \Pi^E_{\mathrm{B}}$ if $c^{\mathrm{E}}_u < c^{\mathrm{I}}_u$).

From proposition 1 we infer that input prices are irrelevant for the entrant's make-or-buy decision. Furthermore, from (11) we infer that input prices do not have an impact on social welfare. Hence, input prices are irrelevant not only for the entrant's make-or-buy decision, but also for the regulator's goal to maximize social welfare. The reason is that a marginal change in input price causes a unit increase in incumbent's profits and a unit decrease in consumer surplus. As social welfare is the unweighted sum of profits and consumer surplus, it is thus not affected by a marginal change in input prices.

It is of high interest to examine the impact of the entrant's efficient make-or-buy decision on social welfare. When the entrant prefers to make the upstream input itself, social welfare is given by (5) and when the entrant prefers to buy the upstream input from the incumbent, social welfare is given by (11). By comparing (5) and (11), we can state the following proposition:

PROPOSITION 2: *Regardless of the established price (w) of the upstream input: (a) the society prefers the entrant to buy the upstream input from the incumbent when the incumbent is the least-cost supplier of the input (i.e.* $SW_B > SW_M$ *if* $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$*) and (b) the society prefers the entrant to make the upstream input itself when it is the least-cost supplier of the input (i.e.* $SW_M > SW_B$ *if* $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$*).*

From Proposition 1 and 2, we infer that if $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$ both the entrant's profits and social welfare are maximized when the entrant chooses to buy the upstream input from the incumbent and if $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$ both the entrant's profits and social welfare are maximized when the entrant chooses to make the upstream input itself. Hence, the maximization of social welfare is in line with the entrant's efficient make-or-buy decision.

PROPOSITION 3: *The efficient make-or-buy decision undertaken by the entrant is always socially optimal.*

Proposition 3 presents another very significant finding: although access price regulation neither affects the efficient make-or-buy decision undertaken by the entrant nor the social welfare, the regulator always succeeds in fulfilling the maximization of social welfare. When $c_u^{\mathrm{E}} < c_u^{\mathrm{I}}$ the entrant chooses to make the upstream input and as a result it invests in alternative infrastructure, which is socially optimal. In this case, the regulator's twofold aim is fulfilled and the trade-off between service-based and facility-based competition disappears. On the contrary, when $c_u^{\mathrm{I}} < c_u^{\mathrm{E}}$ the entrant chooses to buy the upstream input from the incumbent, which is also socially optimal. In this case, the society only enjoys the short-run benefits from service-based competition.

However, from (8) and (10) we infer that when the entrant chooses to buy the input, access price regulation affects both the incumbent's profits and consumer surplus. In particular, there is a transfer of money from consumers to incumbent, which equals the input price. Hence, the entrant passes on the cost of buying the input to consumers. If the regulator's priority is to maximize consumers' utility, it should set the input price to zero. Alternatively, if the regulator can bind the incumbent to invest its extra profits from the upstream market to network facilities, it may set the access price to a level equal or below $CS_B$. The latter policy induces investments in network infrastructures by the incumbent but does not provide incentives for facilities-based competition. The reason is that the incumbent's unit cost of producing the upstream input is expected to decrease and as a result the entrant will find it profitable to buy the input from the incumbent. Another alternative is that the regulator sets a positive input price that allows the incumbent to recover the fixed costs that typically incurs in practice. In each case, the regulator's priority does not affect social welfare and the entrant's profits, but only consumer surplus and the incumbent's profits.

## 4. Conclusions

The primary objective of this paper was to examine whether input prices are irrelevant from regulatory point of view. The ultimate goal of regulators is to maximize social welfare and to promote investments in alternative infrastructures (especially by entrants, in order to induce facilities-based competition). Sappington (2005) uses the Hotelling model to show that input prices are irrelevant for an entrant's decision to make or buy an upstream input required for downstream production. Using the same model, we showed that input prices are also irrelevant for the maximization of social welfare. By combining Sappington's results with ours, we have concluded that input prices are irrelevant from the regulatory point of view.

Another interesting result was that the entrant's efficient make-or-buy decision is always socially optimal. In other words, the entrant's efficient decision always maximizes social welfare. Therefore, when the entrant prefers to make the upstream input itself, both regulatory goals are fulfilled. This result is very significant because the regulator succeeds in fulfilling its goals without affecting either the entrant's efficient make-or-buy decision or the social welfare. However, when the entrant prefers to buy the upstream input from the incumbent, the regulator's goal to promote facilities-based competition cannot be fulfilled.

In addition, we showed that, although input prices are irrelevant for make-or-buy decisions and for the maximization of social welfare, it can be used by the regulator in order to fulfill other goals, such as the maximization of consumer surplus, the promotion of investments by the incumbents and the recovery of the fixed cost that the incumbents typically incur in practice.

The main implication from this article is that regulators should perceive the particular model that characterizes the retail competition between the providers in order to forecast the impact of access price regulation on providers' strategies and consumers' utility, which in turn affect the fulfillment of regulators' goals.

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## Appendix

*Proof of Lemma 1*

Let $\hat{L} \in [0,1]$ denote the location of the consumer that is indifferent between purchasing from the incumbent and the entrant when the entrant chooses to make the upstream input. See Sappington (2005) for equations (1) to (3) and the equation that gives the location of the indifferent consumer. Consumer surplus is given by

(A1) $$CS = N\{\int_{o}^{\hat{L}}[v - P_1 - t(L-0)]dL + \int_{\hat{L}}^{1}[v - P_2 - t(1-L)]dL\} \Rightarrow$$

(A2) $$CS = N[v + \hat{L}(P_2 - P_1) - P_2 - \frac{\hat{L}^2}{2} + \frac{(1-\hat{L})^2}{2}]$$

Substituting (1) in (A2) provides:

(A3) $$CS_{\mathrm{M}} = N[v - t - \frac{c_u^I + 2c_u^{\mathrm{E}}}{3} + \frac{(c_u^{\mathrm{E}} - c_u^I)^2}{18t}]$$

Social welfare is the sum of both providers' profits and consumer surplus.

*Proof of Lemma 2*

See Sappington (2005) for equations (6) to (9) and the equation that gives the location of the indifferent consumer when the entrant chooses to buy the upstream input from the incumbent. Substituting (6) in (A2) provides the consumer surplus when the entrant chooses to buy the upstream input from the incumbent.

(A4) $$CS_B = N(v - w - t)$$

Social welfare is the sum of both providers' profits and consumer surplus.

*Proof of Proposition 1*

See Sappington (2005).

*Proof of Proposition 2*

From equations (5) and (11) in the text:

(A5) $$SW_M >=< SW_B$$

(A6) $$N[v - \frac{c_u^I + 2c_u^{\mathrm{E}}}{3} + \frac{(c_u^{\mathrm{E}} - c_u^I)^2}{6t}] >=< N(v - c_u^I)$$

(A7) $$\frac{1}{3}(c_u^{\mathrm{E}} - c_u^I)(\frac{c_u^{\mathrm{E}} - c_u^I}{2t} - 2) >=< 0$$

Like Sappington (2005), we assume that both the incumbent and entrant serve retail consumers in equilibrium. Hence, $|c_u^j - c_u^i| < 3t$ (*for* $i, j = I, E,\ i \neq j$). From (A7) we infer that:

a. if $c_u^{\mathrm{E}} = c_u^I$, then $SW_M = SW_B$

b. if $c_u^{\mathrm{E}} > c_u^I$, then $SW_M < SW_B$

c. if $c_u^{\mathrm{E}} < c_u^I$, then $SW_M > SW_B$

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# Investments in Next Generation Access infrastructures under regulatory uncertainty

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ABSTRACT

This article studies the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in NGA networks. Thus, a regulatory non-commitment setting in which the regulator sets the access price after the deployment of the NGA network is used. In particular, it is assumed that the regulator sets the access price at the marginal cost of providing the access with some probability and gives an access markup, which equals the average cost of the investments, with the complementary probability. It is found that when the slope of the marginal investment cost function is not particularly steep in relation to the impact of investments on demand, the incumbent underinvests compared to the socially optimal investment level. On the contrary, when the impact of investments on demand is low in relation to the slope of the marginal investment cost function, the incumbent may overinvest or underinvest depending on the probability of incorporating an access markup into the access price.

**Keywords:** access regulation, dynamic efficiency, investment incentives, regulatory uncertainty, social welfare, telecommunications

**JEL classification:** L43, L51, L96

## 1. Introduction

The migration from the legacy copper access networks to fibre access networks capable of providing high-speed broadband services (hereafter referred to as Next Generation Access (NGA) networks[1]) has induced a growing interest in the relationship between access regulation and investment incentives.[2] The related literature concludes that the regulators' two fold-goal to foster competition and encourage efficient and timely investments in NGA networks is related to the common trade-off between static and dynamic efficiency.

In particular, mandated access at cost-based prices reduces the use of monopoly power over the access infrastructure by preventing the incumbent from foreclosing the entrants from the downstream (retail) market. Cost-based access regulation thus leads to sustainable service-based competition within one network, and hence, improves static efficiency (Valletti, 2003; Bouckaert, van Dijk and Verboven, 2010). However, mandating the access at cost-based prices discourages both incumbents and potential entrants to invest in new access infrastructures (Jorde, Sidak and Teece, 2000). According to Cave and Prosperetti (2001), the reason for this negative relationship between access regulation and incumbents' incentives to invest is that the incumbents anticipate that they will be required to offer access to their rivals at cost-based prices. Therefore, potential entrants, who can free-ride on the incumbent's network, will wait for the incumbent to invest in new access infrastructures and then seek access (Valletti, 2003). The conclusion is that cost-based access regulation, which is limited to promote service-based competition, leads to losses in dynamic efficiency (Bouckaert, van Dijk and Verboven, 2010).

For this reason, the ongoing research on this area is gradually shifting its focus from assessing the efficiency implications of cost-oriented access schemes to proposing new regulatory approaches that may promote both static and dynamic efficiency. This implies that access regulation of NGA services is still considered necessary for inducing socially optimal investments. In this context, a first set of papers studies the impact of an investment-contingent access price on investment incentives and competition. Henriques (2011) and Sauer (2011) show that contrary to a fixed access charge, an access fee that is contingent on firms' (non-overlapping) investments can implement the socially efficient investment level. This outcome holds either if the access charge depends on the investments of both the incumbent and the entrant (former article) or on each operator's own investment level (latter article).

Nitsche and Wiethaus (2011) introduce uncertainty about the success of NGA investments and focus on an incumbent's investment incentives in order to study the efficiency outcomes of different regulatory regimes. They show that under an access price that spreads investment costs over total output quantities (i.e. an investment-contingent access scheme), a regime with fully distributed costs or a regulatory holiday induce highest investments, followed by risk-sharing and forward-looking cost-based regulation. In addition, combining strong competitive

[1] According to EU Commission (2010) NGA networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network.

[2] See Cambini and Jiang (2009) for a recent and comprehensive review of the theoretical and empirical literature on the relationship between broadband investment and regulation.

intensity with reasonable investment incentives indicates that a risk sharing approach induces highest consumer surplus, followed by regimes with fully distributed costs, regulatory holiday and forward-looking cost-based regulation. Bender (2011) extends the work of Nitsche and Wiethaus by introducing horizontal product differentiation and assuming that the entrant may not share the investment costs with the incumbent but bears a fixed part of the investment costs (i.e. a cooperation regime). The author finds that there is no single regime which always yields highest investments as full distribution, as well as, cooperation might maximize the investment incentives, whereas the optimal regulatory policy is mainly subject to the degree of product differentiation.

It is important to note that the abovementioned articles, which are based on an investment-contingent access price, assume that the regulator can make *ex ante* credible commitments. This implies that the regulator sets the access price prior to the investments, and hence, the firms invest under regulatory certainty. Although this modeling setup is consistent with the European Commission (EC) Recommendation on regulated access to NGA (EU Commission, 2010), it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period (WIK, 2009). Therefore, in providing greater regulatory certainty the regulator has to make another trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare (OPTA, 2010).

As a result, a second set of papers studies the impact of access regulation on investment incentives under regulatory non-commitment. In this case, it is assumed that the regulator cannot make *ex ante* credible commitments, and hence, the firms invest prior to the regulation of the access. Foros (2004) studies the impact of cost-based access regulation on an incumbent's incentives to invest in network upgrade in the presence of spillover effects. It is found that when the incumbent is much more efficient in providing value-added services than the entrant, then the incumbent can foreclose the entrant from the market by overinvesting in quality. In addition, Kotakorpi (2006) points out that, under cost-based regulation, the incumbent underinvests in relation to the socially optimal level. Mizuno and Yoshino (2012) allow an enlarged range of spillovers in order to examine the impact of regulatory non-commitment on the properties of a welfare maximizing access charge. They find that when the degree of spillover is small and the incumbent's investment cost is high (respectively, low), the incumbent has an incentive to utilize regulatory non-commitment to induce a high (respectively, low) access charge by overinvesting (respectively, underinvesting) in infrastructure.

Contrary to the three previous articles that use a fixed access charge, Klumpp and Su (2010) assume an investment-contingent access price which is revenue-neutral. This implies that each downstream firm contributes to the depreciation of the investment costs according to its market share. They show that, under this rule, the incumbent chooses a higher investment level compared to that of a monopolist and its investment incentives increases with the number of downstream competitors. Thus, they argue that a policy of revenue-neutral open access can increase both static and dynamic efficiency. Sarmento and Brandao (2007) compare the investment and competition outcomes of an access price which equals the marginal cost of providing the access plus the average cost of the investments with those derived by the retail-minus regulation and the deregulation of the access price. They conclude that retail-minus regulation leads to better results than cost-based regulation in terms of investment level and consumer surplus as long as the regulator carefully defines the retail-minus instrument.

Last, Cambini and Silvestri (2012) also study the impact of regulatory non-commitment on the incumbent's investment incentives, but their research focuses on the timing of the investments rather than on the extent of NGA deployment. For this reason, they use a dynamic setting with demand uncertainty in order to compare the efficiency outcomes of three different regulatory regimes: full regulation (the NGA network is regulated), partial regulation (the NGA network is unregulated) and risk sharing (fixed investment costs are shared but there are no side payments between firms for the use of the NGA). They conclude that the investment is always undertaken later than in the social optimum in all regulatory regimes.

It can be thus concluded that the related literature provides useful results concerning the effectiveness of particular access pricing schemes and certain regulatory regimes on promoting both static and dynamic efficiency. However, the articles that examine the relationship between access regulation and investment incentives under regulatory non-commitment take the regulator's decision as given. As a result, they fail to take into account the fact that there is uncertainty about the access pricing formula once the investments are in place. In particular, some articles (Foros, 2004; Kotakorpi, 2006; Mizuno and Yoshino, 2012) assume that the firms anticipate that the regulator will set the welfare maximizing access price, whereas others (Klumpp and Su, 2010; Sarmento and Brandao, 2007) assume that the investment-contingent access price is *ex ante* known. Therefore, the difference in the results of the commitment and the non-commitment models is mainly driven by the sequential timing of the games rather than by the regulatory uncertainty of the non-commitment games.

On the contrary, this paper takes into account the regulator's incentives to deviate from an investment-contingent access pricing rule (which implies that the regulator compensates the incumbent for the investment risks) by setting the social welfare maximizing access price once the investments are in place. In particular, it is assumed that the regulator may implement the access rule proposed by Sarmento and Brandao (2007) or set the welfare maximizing access price. This implies that when the incumbent invests prior to the regulation of the access, there is an uncertainty about the level of the access charge. The aim of this paper is to model such regulatory uncertainty and to study its impact on an incumbent's investment incentives and on the subsequent welfare outcomes.

It is found that when the probability of compensating the incumbent for the investment risks increases, the incumbent's investment incentives increase and the socially optimal investment level decreases. In addition, the critical value of such probability that makes the incumbent undertake the socially optimal (efficient) investments is decreasing in the slope of the marginal investment cost function and increasing in the effect of the investments on demand. Thus, when the slope of the marginal investment cost function is not particularly steep in relation to the positive impact of investments on demand, the incumbent always underinvests compared to the socially optimal investments. On the contrary, when the impact of investments on demand is low in relation to the slope of the marginal investment cost function, the incumbent overinvests for high probability of setting the access pricing rule of Sarmento and Brandao (2007) and underinvests for low probability values.

It is thus obvious that the effectiveness of access price regulation on promoting both static and dynamic efficiency (i.e. inducing the socially optimal investments in NGA networks) does not only depend on the underlying demand and cost structure (as the related literature concludes), but is also dependent on the expected probability of deviating from a particular investment-contingent access pricing rule.

The rest of the paper is organized as follows. Section 2 gives an outline of the basic assumptions and definitions of the model. Section 3 provides the equilibrium of the game when the regulatory uncertainty is taken into account. Section 4 compares the privately and the socially optimal investment levels derived in section 3 in order to draw regulatory implications. The last section summarizes the key findings of this article.

## 2. The model

This section presents a simple model used in order to assess the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in new access infrastructures. In particular, the model used in this paper is quite similar to that of Sarmento and Brandao (2007) in terms of demand and cost structure, as well as, the timing of the game.

### *2.1. Demand side*

The retail (downstream) market is characterized as an unregulated duopoly market in which the incumbent (the subsidiary firm of the upstream monopolist) and the entrant (the independent firm) choose quantities simultaneously and independently (i.e. firms compete á la Cournot). It is further assumed that since the prospective investors in NGA networks are for large part the former incumbent operators (OPTA, 2010), the incumbent decides its optimal NGA investment level first and then the entrant seeks access to the incumbent's NGA network.[3]

The inverse demand function is given by $p = 1 + \beta I - (q_1 + q_2)$, where $p$ is the retail market price, $q_1$ and $q_2$ are the quantities supplied by the incumbent and the entrant respectively, $I$ represents the level of the NGA investments undertaken by the incumbent, and $\beta$ represents the impact of a marginal change in the investment level on the retail price (ceteris paribus). It is also assumed that $\beta > 0$, which implies that an increase in the NGA investment level leads to an outward parallel shift in the demand that benefits both retailers.

[3] This assumption reflects the EU Commission's argument that in most cases NGAs are the result of an upgrade of an already existing copper access network. The reason is that the former incumbent operators usually upgrade their access networks by replacing part of the copper networks with optical elements (i.e. FTTC variants). On the contrary, a narrower definition of NGA networks (i.e. FTTH/B) may reflect the fact that alternative operators seem to dominate such network deployment. However, the results of this paper do not change qualitatively if we assume that the entrant decides its optimal NGA investment level first and then the incumbent seeks access to the entrant's NGA network.

### *2.2. Supply side*

The NGA deployment is continuous where a larger $I$ reflects a fibre deployment closer to the consumers' premises. The incumbent faces a quadratic NGA investment cost function with respect to $I$, given by $C(I) = \varphi I^2/2$, with $\varphi > 0$. The cost parameter $\varphi$ represents the slope of the marginal investment cost function, and hence, as $\varphi$ increases the total investment costs increase as well (for a given investment level). For this reason, the term "investment cost parameter" refers to $\varphi$, whereas the term "investment costs" refers to the total cost of NGA investments denoted by $C(I)$. The convex form of the NGA investment cost function reflects the fact that fibre deployment becomes marginally more expensive as it is being laid down towards consumers' premises. It is further assumed that the NGA investment level does not have any impact on the (fixed) marginal cost of providing the access denoted by $c$, ($c<1$). In addition, the production of one unit of the retail service requires one unit of the upstream input (fixed coefficients technology).

The access price that the entrant should pay to the incumbent in order to have access to the incumbent's NGA network is denoted by $w$, assuming $w \geq c$. The regulator defines the access price as the marginal cost of providing the access ($c$) plus a fraction $k$ of the total investment costs, that is $w = c + kC(I)$, with $k < 1$. If $k = 0$, the regulator sets the access price at the marginal cost of providing the access, whereas if $k \in (0,1)$, the regulator (partially or fully) compensates the investor for the uncertainty of NGA investments.

Last, the quality of the input sold by the monopolist is the same whether it is sold to the incumbent or to the entrant. In addition, the cost of all other inputs is equal for both retailers and normalized to zero.

### *2.3. Timing of the game*

This paper falls into the literature which assumes that the regulator cannot make *ex ante* credible commitments on its future interventions, and hence, the incumbents decide their optimal investment level prior to the regulation of the access. Therefore, the timing of the game is as follows:

- Firstly, the incumbent decides the investment level $I$ that maximizes its profits.
- Secondly, the regulator chooses an access price $w$ that may incorporate a risk premium reflecting the uncertainty of NGA investments, i.e $k \in [0,1)$.
- Finally, the retail price and outputs of the firms are defined by Cournot competition between downstream firms.

According to Sarmento and Brandao (2007), the regulator sets the access price equal to the marginal cost of providing the access plus the average cost of the investments. Therefore, $k = (1/I)$ and $w = c + (\varphi I/2)$. This definition of the access price implies that the average cost of the investments can be seen as an access markup that fully compensates the investor for the uncertainty of NGA investments. However, Cave and Prosperetti (2001), as well as, Foros (2004) argue that the regulator is expected to set the access price at the marginal cost of providing the access (i.e. $k = 0$) in order to maximize social welfare as soon as the incumbent invests in NGA network.[4] In this paper, it is assumed that the incumbent anticipates that $k=(1/I)$ with probability $\alpha$ and $k=0$ with probability $(1-\alpha)$, where $\alpha \in [0,1]$.[5] In the former case, the regulator fully compensates ("FC") the incumbent for the investment risks; and in the latter case, the regulator sets the social welfare maximizing access price, which implies that the regulator does not compensate ("NC") the incumbent for the uncertainty of NGA investments.

The profit functions of the incumbent (firm 1) and the entrant (firm 2) are given, respectively, by:

$$\pi_1 = (p-c)q_1 + (w-c)q_2 - \varphi I^2/2 \tag{1}$$

$$\pi_2 = (p-w)q_2 \tag{2}$$

Therefore, when $w=c+(\varphi I/2)$, the two firms make the following profits (gross of investment costs):

$$\pi_1^{FC} = [(p^{FC}-c)q_1^{FC} + (\varphi I/2)q_2^{FC}]\alpha \tag{3}$$

$$\pi_2^{FC} = [(p^{FC}-c-\varphi I/2)q_2^{FC}]\alpha \tag{4}$$

whereas, when $w=c$ the respective profit functions are (gross of investment costs):

$$\pi_1^{NC} = [(p^{NC}-c)q_1^{NC}](1-\alpha) \tag{5}$$

$$\pi_2^{NC} = [(p^{NC}-c)q_2^{NC}](1-\alpha) \tag{6}$$

It is obvious that total profits of the incumbent and the entrant are given, respectively, by:

$$\pi_1 = \pi_1^{FC} + \pi_1^{NC} - \varphi I^2/2 \tag{7}$$

$$\pi_2 = \pi_2^{FC} + \pi_2^{NC} \tag{8}$$

## 3. Equilibrium of the game

The aim of this paper is to assess the impact of regulatory uncertainty on the incumbent's incentives to invest in NGA networks and to draw regulatory implications from the comparison between the NGA investment level chosen by the incumbent (i.e. the privately optimal level) and the respective level of NGA investments that maximizes social welfare (i.e. the socially optimal level).

The backward induction technique is used to find the equilibrium of the whole game. Therefore, the analysis begins with the computation of the retail price and the output of the firms as a function of the investment level and the access price. Then, the regulator chooses an access price $w$ that may incorporate a risk premium reflecting the uncertainty of NGA investments. In particular, the access price is $w=c+(\varphi I/2)$ with probability $\alpha$ or $w=c$ with probability $(1-\alpha)$. Hence,

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[4] Indeed, it is shown in Appendix A1 that social welfare is maximized for $k<0$. However since it is generally assumed that $w \geq c$, the access price that maximizes social welfare is $w=c$.

[5] This is the typical way that the related literature handles the imperfect commitment to access price. For a particular example, see Vareda (2010).

the profits functions of both retailers are derived as a function of the investment level and the probability $\alpha$. Taking into account the derived results, the privately and socially optimal investment levels are obtained as a function of $\alpha$.

### *3.1. Retail competition*

Substituting $p = 1 + \beta I - (q_1 + q_2)$ in Eqs. (1) and (2), and taking the first order condition with respect to $q_1$ and $q_2$, respectively, gives the reaction function of each firm to the quantity supplied by the other. Solving simultaneously the reaction functions for both operators yields the output of the firms and the subsequent retail price:

$$q_1 = (1 + \beta I + w - 2c)/3 \tag{9}$$

$$q_2 = (1 + \beta I - 2w + c)/3 \tag{10}$$

$$p = (1 + \beta I + w + c)/3 \tag{11}$$

### *3.2. Access price regulation*

In this stage the regulator sets the price that the entrant should pay to the incumbent in order to have access to the NGA network. In particular, the regulator may compensate the incumbent for the NGA investment risks or set the access price equal to the marginal cost of providing the access in order to maximize social welfare. Substituting $w = c + (\varphi I / 2)$ in Eqs. (9)-(11) gives the output of the firms and the subsequent retail price when the access price includes a markup equal to the average cost of the investments. Hence:

$$q_1^{FC} = (1 + \beta I - c + \varphi I / 2)/3 \tag{12}$$

$$q_2^{FC} = (1 + \beta I - c - \varphi I)/3 \tag{13}$$

$$p^{FC} = (1 + \beta I + 2c + \varphi I / 2)/3 \tag{14}$$

On the contrary, when the regulator does not compensate the incumbent for the investment risks, the output of the firms and the subsequent retail price are derived by substituting $w = c$ in Eqs. (9)-(11). Hence:

$$q_1^{NC} = (1 + \beta I - c)/3 \tag{15}$$

$$q_2^{NC} = (1 + \beta I - c)/3 \tag{16}$$

$$p^{NC} = (1 + \beta I + 2c)/3 \tag{17}$$

Given that the total output in the compensation case is given by $Q^{FC} = \left(q_1^{FC} + q_2^{FC}\right)$ and in the non-compensation case by $Q^{NC} = \left(q_1^{NC} + q_2^{NC}\right)$, the levels of total output ($Q$), consumer surplus (*CS*), each provider's profits, and social welfare (*SW*) are as follows:

$$Q = \alpha Q^{FC} + (1-\alpha) Q^{NC} = (2 + 2\beta I - 2c - \alpha \varphi I / 2)/3 \tag{18}$$

$$CS = \left[ \alpha \left( Q^{FC} \right)^2 + (1-\alpha) \left( Q^{NC} \right)^2 \right] / 2 \Rightarrow$$
$$CS = \left[ (1-c)(16-16c+32\beta I - 8\alpha\varphi I) + I^2 (16\beta^2 - 8\alpha\beta\varphi + \alpha\varphi^2) \right] / 72 \tag{19}$$

$$\pi_1 = [(1-c)(4-4c+8\beta I+10\alpha\varphi I) + 2\varphi I^2 (5\alpha\beta - 9) + I^2 (4\beta^2 - 5\alpha\varphi^2)] / 36 \tag{20}$$

$$\pi_2 = [(1-c)(1-c+2\beta I-2\alpha\varphi I) + I^2 (\alpha\varphi^2 - 2\alpha\beta\varphi + \beta^2] / 9 \tag{21}$$

$$SW = \pi_1 + \pi_2 + CS \Rightarrow$$
$$SW = \left[ (1-c)(32-32c+64\beta I - 4\alpha\varphi I) + I^2 (32\beta^2 - 4\alpha\beta\varphi - 36\varphi - \alpha\varphi^2) \right] / 72 \tag{22}$$

### *3.3. Privately optimal investments*

Taking the first order condition of Eq. (20) with respect to $I$, gives the NGA investment level that maximizes the incumbent's (private) profits:

$$I^* = (1-c)(4\beta + 5\alpha\varphi) / (18\varphi + 5\alpha\varphi^2 - 4\beta^2 - 10\alpha\beta\varphi) \tag{23}$$

It is obvious that, as long as $X \equiv 18\varphi + 5\alpha\varphi^2 - 4\beta^2 - 10\alpha\beta\varphi > 0$, the incumbent's profit is a concave function of $I$, and hence, there exists a unique equilibrium in which the incumbent chooses a positive NGA investment level. In addition, taking the first derivative of Eq. (23) with respect to $\alpha$ yields:

$$\partial I^* / \partial \alpha = 10\varphi(1-c)(9\varphi + 2\beta^2 - 2\beta\varphi) / (X^2) > 0 \tag{24}$$

From Eq. (24) it can be deduced that as $\alpha$ increases, the incumbent chooses a higher NGA investment level. In other words, a higher certainty about the compensation of the incumbent leads to a higher NGA deployment. In addition, the level of social welfare that corresponds to the privately optimal investments is derived by substituting $I^*$ into Eq. (22). Therefore:

$$SW^* = \varphi(1-c)^2 (100\alpha^3\beta\varphi^2 - 125\alpha^3\varphi^3 + 880\alpha^2\beta^2\varphi - 1720\alpha^2\beta\varphi^2 + 800\alpha^2\varphi^3$$
$$-1260\alpha^2\varphi^2 - 16\alpha\beta^2\varphi - 7488\alpha\beta\varphi + 5760\alpha\varphi^2 - 576\beta^2 + 10368\varphi) / (72X^2) \tag{25}$$

Although this section pointed out the significance of the regulatory uncertainty on the incumbent's incentives to invest in NGA networks, a more elaborate analysis is needed in order to examine such relationship from a social perspective.

### *3.4. Socially optimal investments*

The socially optimal investment level is derived by taking the first order condition of Eq. (22) with respect to $I$. Hence, the NGA investment level that maximizes social welfare is given by:

$$I^{**} = (1-c)(32\beta - 2\alpha\varphi) / (36\varphi + \alpha\varphi^2 + 4\alpha\beta\varphi - 32\beta^2) \tag{26}$$

Equation (26) states that the NGA investment level that maximizes social welfare is positive as long as: (i) the investment cost parameter, $\varphi$, is not extremely high in relation to the impact of investments on demand (i.e. $\varphi < 16\beta/\alpha$); and (ii) social welfare is a concave function of $I$ (i.e. $Y \equiv 36\varphi + \alpha\varphi^2 + 4\alpha\beta\varphi - 32\beta^2 > 0$). A necessary and sufficient condition which ensures that $X$ and $Y$ are both positive is $\varphi > \varphi_L$, where $\varphi_L = \left(2\sqrt{\alpha^2\beta^2 + 8\alpha\beta^2 + 18\alpha\beta + 81} - 2\alpha\beta - 18\right)/\alpha$.[6]

**Remark 1.** *Assuming that the investment cost parameter is higher than the critical value $\varphi_L$ ensures that the privately and the socially optimal investment levels are both positive as long as the investment cost parameter is not extremely high in relation to the impact of investments on demand.*

Remark 1 implies that the higher the impact of the investments on demand, the higher the investment cost parameter should be in order to ensure that the incumbent will choose a positive NGA investment level that maximizes either its profits or social welfare. Therefore, given that the investment cost parameter is not extremely high in relation to the impact of investments on demand (i.e. $\varphi < 16\beta/\alpha$), the assumption $\varphi > \varphi_L$ ensures that $X, Y > 0$.

Furthermore, taking the first derivative of Eq. (26) with respect to $\alpha$ yields:

$$\partial I^{**}/\partial\alpha = 8\varphi(c-1)(9\varphi + 8\beta^2 + 4\beta\varphi)/(Y^2) < 0 \tag{27}$$

From Eq. (27) it can be deduced that there is a negative relationship between $\alpha$ and $I^{**}$ since $c < 1$. This implies that the socially optimal investment level increases with an increase in the probability of setting the access price equal to the marginal cost of providing the access. Therefore, a marginal increase in $\alpha$ positively affects the private investment incentives and negatively affects the socially optimal investments. This is an expected result since the incumbent's profits increase with an increase in the access price, whereas social welfare increases with a decrease in the access price.

However, for any given value of $\alpha$, the level of social welfare that corresponds to the socially optimal investments reflects the maximum social welfare outcome. This level is derived by substituting $I^{**}$ into Eq. (22):

$$SW^{**} = \varphi(1-c)^2(288 + 8\alpha\varphi + \alpha^2\varphi)/(18Y) \tag{28}$$

Since the aim of this paper is to study the impact of the regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in NGA networks, the next section derives the value of $\alpha$ that results in the same privately and socially optimal investment level.

## 4. Comparison of privately and socially optimal investments

This section assesses the value of $\alpha$ that makes the incumbent undertake the socially optimal investments in NGA networks. The comparison of $I^*$ and $I^{**}$ shows that:

$$I^{**} - I^* = 3Z\varphi(1-c)/(XY) \tag{29}$$

[6] The proof is given in Appendix A2.

where $Z = 144\beta + 52\alpha\beta\varphi - 72\alpha\varphi - 5\alpha^2\varphi^2 - 56\alpha\beta^2$ (30)

Given that $X, Y > 0$ and $c < 1$, it can be concluded that when $Z = 0$, the incumbent undertakes the socially optimal investments in NGA networks, whereas when $Z > 0$ (respectively, $Z < 0$) the incumbent underinvests (respectively, overinvests) compared to the socially optimal investment level.

In addition, the comparison of $SW^*$ and $SW^{**}$ shows that:

$$SW^{**} - SW^* = [Z\varphi(1-c)]^2 / (72X^2Y) \tag{31}$$

From Eq. (31) it can be inferred that the society is always better off when the incumbent undertakes the socially optimal investment level rather than the respective level that maximizes its profits, with the exception of $Z = 0$. In the latter case, the incumbent undertakes the socially optimal investments, and hence, the derived social welfare level reaches the maximum welfare outcome. It can be thus deduced that the incumbent's choice to deviate from the socially optimal investment level results in welfare losses which reflects the standard trade-off between static and dynamic efficiency.

Solving Eq. (30) with respect to $\alpha$ derives the value of the probability of including a markup into the access price that tackles this efficiency trade-off. In other words, the value of $\alpha$ which leads to $I^{**} = I^*$ and $SW^{**} = SW^*$ (or equivalently to $Z = 0$) is given by:

$$\tilde{\alpha} = \left[\begin{matrix} 26\beta\varphi - 36\varphi - 28\beta^2 \pm \\ 2\sqrt{196\beta^4 - 364\beta^3\varphi + 169\beta^2\varphi^2 + 504\beta^2\varphi - 288\beta\varphi^2 + 324\varphi^2} \end{matrix}\right] / (5\varphi^2) \tag{32}$$

Let $\tilde{\alpha}$ denotes the positive value of $\alpha$ that induces the incumbent to undertake the socially optimal investments.[7] Therefore:

$$\tilde{\alpha} = \left[\begin{matrix} 26\beta\varphi - 36\varphi - 28\beta^2 + \\ 2\sqrt{196\beta^4 - 364\beta^3\varphi + 169\beta^2\varphi^2 + 504\beta^2\varphi - 288\beta\varphi^2 + 324\varphi^2} \end{matrix}\right] / (5\varphi^2) \tag{33}$$

It can be thus deduced that, when $\alpha > \tilde{\alpha}$ (respectively, $\alpha < \tilde{\alpha}$), the value of $Z$ is negative (respectively, positive), and hence, the NGA investment level chosen by the incumbent is higher (respectively, lower) than the socially optimal one. This implies that any deviation from the socially optimal investments leads to welfare losses (i.e. $SW^{**} > SW^*$ for $\alpha \neq \tilde{\alpha}$). The derived value of $\tilde{\alpha}$ is significantly affected by the impact of the investments on demand and the investment cost parameter. In particular, the value of $\tilde{\alpha}$ is positively affected by an increase in $\beta$ and negatively affected by an increase in $\varphi$ (ceteris paribus).[8] This implies that, for a given investment cost parameter, higher consumers' valuation for the NGA services results in higher $\tilde{\alpha}$, which in turn leads to higher efficient investment levels. In other words, higher values of $\beta$, make the investments more socially desirable, and hence, the socially optimal investment level is achieved for a

[7] This result is numerically proven in Appendix B. In particular, the positive (respectively, negative) value of $\tilde{\alpha}$ is decreasing (respectively, increasing) function of $\varphi$. However, there is always one positive and one negative value of $\tilde{\alpha}$ since they both tend to zero as $\varphi$ tends to infinity.

[8] The proof is given in Appendix A3.

higher probability of compensating the incumbent for the investment risks. This result positively affects the incumbent's investment incentives, and hence, the achieved efficient investment level increases as well.

On the contrary, for a given positive impact of the investments on demand, a steeper slope of the marginal investment cost function leads to lower values of $\tilde{\alpha}$. This implies that as the NGA investments become marginally more expensive, the society is better off by a lower NGA deployment which is achieved by a higher probability of setting the access price at the marginal cost of providing the access. Therefore, the efficient NGA investment level is achieved for lower values of $\tilde{\alpha}$.

Figure 1 graphically presents the results of the above analysis concerning the impact of $\beta$ and $\varphi$ on $\tilde{\alpha}$. In particular, it presents the results of the numerical simulations used in order to derive the values of $\tilde{\alpha}$ for different combinations of $\beta$ and $\varphi$ given that $\varphi > \varphi_L(\tilde{\alpha})$.[9]

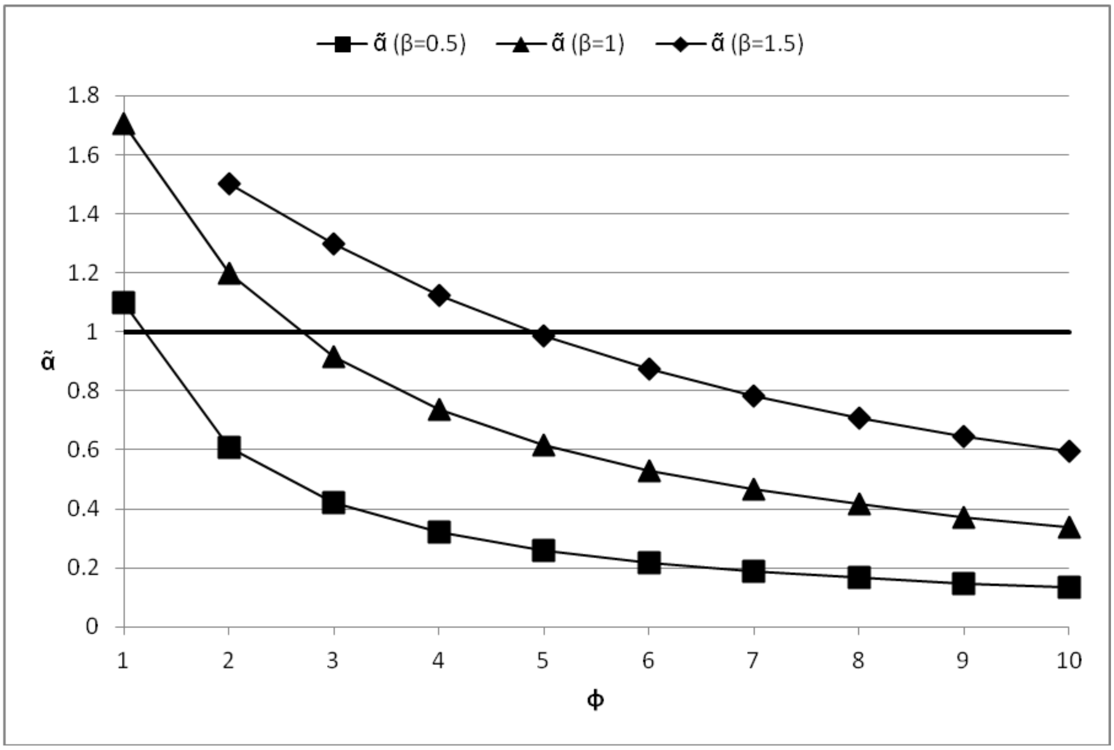


**Fig. 1.** The relationship between $\tilde{\alpha}$ and $\varphi$

Figure 1 graphically verifies the positive relationship between $\tilde{\alpha}$ and $\beta$, as well as, the negative relationship between $\tilde{\alpha}$ and $\varphi$. In addition, it is obvious that there are some combinations of $\beta$ and $\varphi$ which leads to $\tilde{\alpha} > 1$. This implies that for every value of $\beta$ there is at least one value of $\varphi$ that makes $\tilde{\alpha} = 1$. Solving $\tilde{\alpha} = 1$ with respect to $\varphi$ yields:

$$\tilde{\varphi} = \left(26\beta - 36 \pm 6\sqrt{11\beta^2 - 32\beta + 36}\right)/5 \tag{34}$$

[9] Figure 1 is a graphical representation of Tables B1-B3 of Appendix B.

Let $\tilde{\varphi}$ denote the highest value of $\varphi$ that makes the privately and the socially optimal investment levels coincide when $\tilde{\alpha}=1$.[10] Therefore:

$$\tilde{\varphi}=\left(26\beta-36+6\sqrt{11\beta^2-32\beta+36}\right)/5 \tag{35}$$

From Eq. (35) it can be deduced that as long as $\varphi<\tilde{\varphi}$, the value of $\alpha$ that makes the incumbent undertake the socially optimal investments is higher than 1. In other words, when the slope of the marginal investment cost function is not particularly steep in relation to the impact of NGA investments on consumers' willingness to pay, then regulatory certainty about the incorporation of an access markup into the access price (i.e. $\alpha=1$) is not adequate to achieve the efficient investment outcome. This implies that the incumbent always underinvests compared to the socially optimal investment level since $\alpha\in[0,1]<\tilde{\alpha}$. In this case, a higher access markup which leads to $\tilde{\alpha}\leq 1$ seems to be socially desirable. This implies that the combination of a low investment cost parameter and a high impact of investments on demand makes the investments more attractive from a social perspective. Thus, the optimal regulatory policy is to provide the incumbent with significant investment incentives.

In addition, the critical value $\tilde{\varphi}$, which makes the incumbent undertake the socially optimal investments when $\tilde{\alpha}=1$, increases with an increasing rate as $\beta$ increases as well.[11] This implies that as $\beta$ increases, the investment cost parameter should be significantly higher in order to ensure that $\tilde{\alpha}=1$. If the investment cost parameter is higher than the critical value of $\tilde{\varphi}$ given by Eq. (35), then the value of $\alpha$ that makes the incumbent undertake the socially optimal investments is lower than 1. In other words, when the investment cost parameter is relatively high compared to the impact of the investments on demand, the incumbent undertakes the socially optimal investments for a particular $\tilde{\alpha}\in(0,1)$. Therefore, the following proposition can be stated:

**Proposition 1.** *As long as the investment cost parameter is high in relation to the impact of the investments on demand, there is a positive critical value of* $\alpha$*, denoted by* $\tilde{\alpha}\in(0,1)$*, that induces the incumbent to undertake the socially optimal investments. When* $\alpha<\tilde{\alpha}$ *(respectively,* $\alpha>\tilde{\alpha}$*), the incumbent underinvests (respectively, overinvests) compared to the socially optimal investments, and hence, there are welfare losses.*

From proposition 1, it can be deduced that the uncertainty about future regulatory intervention significantly affects the incumbent's expectations, and hence, its decision to undertake the socially efficient investments. Moreover, when the value of $\tilde{\alpha}$ is close to 0, the regulator has significant incentives to set the access price at the marginal cost of providing the access. On the contrary, when the value of $\tilde{\alpha}$ is close to 1, an investment-contingent access price which includes a lower

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[10] Table B5 (see Appendix B) provides the values of $\tilde{\varphi}$ for different values of $\beta$. The discussion following Table B5 proves that: (i) the value of $\tilde{\varphi}$ given by Eq. (35) is the highest one; and (ii) the rejected value of $\tilde{\varphi}$ does not affect the final outcomes.

[11] The proof is given in Appendix A4.

markup than the average cost of the investments and leads to $\tilde{\alpha}=1$ seems to be socially desirable.

As it has been already stated above, the derived value of $\tilde{\alpha}$ is significantly affected by the particular value of the parameters $\beta$ and $\varphi$. Figure 2 presents a representative example of the cases in which the difference between $\beta$ and $\varphi$ is relatively high (i.e. results in $\tilde{\alpha}<1$) since they illustrate the relationship between $I^*$ and $I^{**}$, as well as, $SW^*$ and $SW^{**}$ when $\beta=1$ and $\varphi=6$ (i.e. results in $\tilde{\alpha}=0.530$).

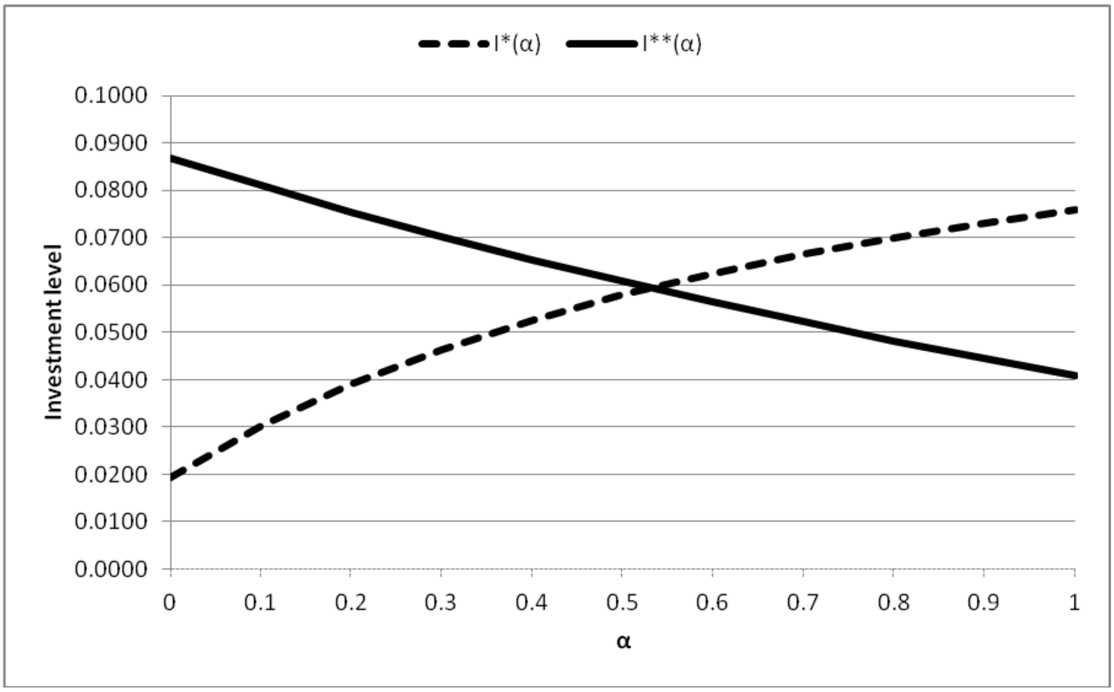


**Fig. 2.** The privately and socially optimal investment levels as a function of $\alpha$ ($\beta=1, \varphi=6, c=0.5$)

Figure 2 numerically verifies the results of Eqs. (24) and (27) which state than an increase in $\alpha$ positively affects the privately investment incentives and negatively affects the socially optimal investments. In addition, it shows that the privately and the socially optimal NGA investment levels coincide for $\tilde{\alpha}=0.530<1$. This is due to the fact that the investment cost parameter is high in relation to the impact of the investments on demand since $\varphi=6>\tilde{\varphi}=2.648$. Therefore, when $\alpha=\tilde{\alpha}$, Eq. (30) yields $Z=0$, and hence, $I^{**}=I^*$. On the contrary, when $\alpha<\tilde{\alpha}$ (respectively, $\alpha>\tilde{\alpha}$), the incumbent underinvests (respectively, overinvests) compared to the socially optimal investment level. The resulting social welfare levels are presented in Fig. 3.

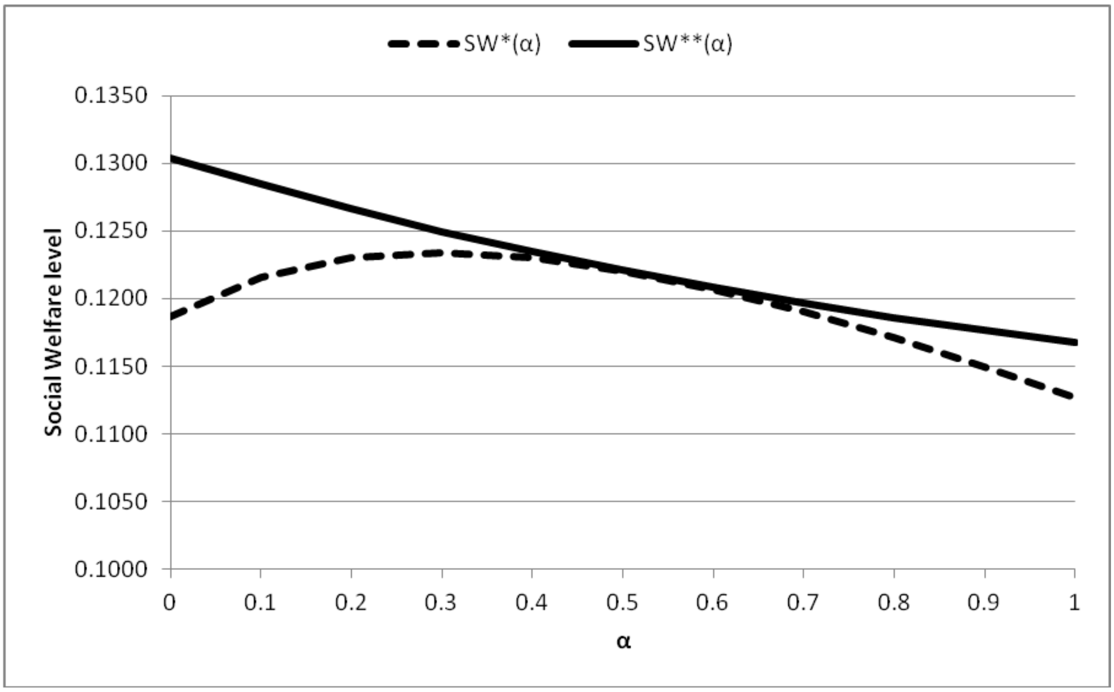


**Fig. 3.** The subsequent social welfare levels as a function of $\alpha$ ($\beta = 1, \varphi = 6, c = 0.5$)

Figure 3 shows that there is a unique positive value of $\alpha$ which leads the social welfare levels derived by the privately and the socially optimal investment choices to coincide (i.e. $SW^{**} = SW^{*}$). In this numerical example, Eq. (31) holds for $\tilde{\alpha} = 0.530$ which implies that the value of $\alpha$ that makes the incumbent undertake the socially optimal investments equals the respective value of $\alpha$ that makes the social welfare levels derived by the privately and the socially optimal investment choices coincide. Therefore, the incumbent not only undertakes the socially optimal investments, but also maximizes the potential social welfare outcome since $I^{**} = I^{*}$ and $SW^{**} = SW^{*}$. In all other cases $SW^{**} > SW^{*}$, which means that the optimal social welfare outcome cannot be achieved with the incumbent's profit maximizing investment level.

## 5. Conclusions

The aim of this paper was to study the impact of regulatory uncertainty on an incumbent's incentives to undertake the socially optimal investments in NGA networks. For this reason, a regulatory non-commitment setting in which the incumbent invests prior to the regulation of the access was used. The related literature discusses the effectiveness of two different regulatory approaches on the regulator's goal to achieve the socially efficient investment level. The first approach supports that the regulator sets a particular investment-contingent access price, which compensates the incumbent for the investment risks, in order to provide significant investment incentives. On the contrary, the second approach argues that the regulator deviates from such *ex ante* known access price (once the investments are in place) by setting the access price at the marginal cost of providing the access (i.e. setting the social welfare maximizing access price).

The main contribution of this paper to the existing literature is that it modeled the more realistic case in which the regulator sets the access price at the marginal cost of providing the access with some probability and gives an access markup, which equals the average cost of the investments, with the complementary probability. Therefore, it is uncertain which of the two assumptions made in the related literature will prevail when the new access infrastructures are in place.

It is found that when the investment cost parameter ($\varphi$) is not high (which implies that the slope of the marginal investment cost function is not particularly steep) in relation to the impact of investments on demand ($\beta$), the incumbent underinvests compared to the socially optimal investment level. The reason is that the critical value of the probability of including an access markup into the access price ($\tilde{\alpha}$), which leads the incumbent to undertake the socially optimal investments, is decreasing in $\varphi$ and increasing in $\beta$. As a result, $\tilde{\alpha} > 1$. This implies that the socially desirable outcome cannot be achieved even if the regulator commits to an access price scheme that includes an access markup equal to the average cost of the investments. In this case, a higher access markup which leads to $\tilde{\alpha} \leq 1$ seems to be socially desirable.

On the contrary, when the investment cost parameter is high and the impact of investments on demand is relatively low, the incumbent may overinvest or underinvest depending on the probability of incorporating the average cost of the investments into the access price. In this case, $\tilde{\alpha} < 1$. In particular, when $\alpha < \tilde{\alpha}$ (respectively, $\alpha > \tilde{\alpha}$), the incumbent underinvests (respectively, overinvests) compared to the socially optimal investment, and hence, there are welfare losses. This implies that regulatory uncertainty significantly affects the incumbent's incentives to undertake the socially optimal investments in NGA networks.

However, it is acknowledged that significant future research is needed. For example, the derived results may change if we take into account the fact that the migration from copper access networks to NGA networks is a slow process (Bourreau, Cambini and Hoernig, 2012). This implies that during the migration phase both the legacy copper access networks and the NGA networks are in operation and are competing for customers. Therefore, the impact of the regulation of the legacy copper networks on the uncertainty about the regulation of the NGA networks should be modeled in order to assess the investment and competition outcomes.[12]

**Acknowledgments**

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[12] See Bourreau, Cambini and Dogan (2012), Brito, Pereira and Vareda (2010, 2012) and Inderst and Peitz (2012) for the impact of the regulation of the legacy network on the firms' investment incentives when the NGA market is left unregulated or when there is an interplay between the access prices of the two networks.

## Appendix A

### *A1. Proof that social welfare is maximized for k<0*.

Substituting Eqs. (9)-(11) into (1) and (2) gives the profit functions of the incumbent and the entrant, respectively, under Cournot competition:

$$\pi_1 = [2+2\beta I(2+\beta I-7c+5w)+2c^2-14c+10w(1+c-w)+9\varphi I^2]/18 \quad \text{(A1)}$$

$$\pi_2 = (1+\beta I-2w+c)^2/9 \quad \text{(A2)}$$

Consumer surplus is given by:

$$CS=(q_1+q_2)^2/2=(2+2\beta I-c-w)^2/18 \quad \text{(A3)}$$

whereas social welfare (*SW*) is the unweighted sum of industry profits and consumer surplus (i.e. $SW=\pi_1+\pi_2+CS$):

$$SW=(8+8\beta^2 I^2-14\beta cI-2\beta wI+16\beta I+5c^2+4cw-14c-w^2-2w+9\varphi I^2)/18 \quad \text{(A4)}$$

Now assume that the regulator sets an access price equal to the marginal cost of providing the access ($c$) plus a fraction $k$ of the total investment costs, that is $w=c+kC(I)$, with $k<1$. Substituting this access price in Eq. (A4) and taking the first order condition with respect to $k$ gives:

$$\partial SW/\partial k=0 \Rightarrow -\varphi I^2(2+2\beta I-2c+k\varphi I^2)/36=0 \Rightarrow$$

$$k^*=-2(1+\beta I-c)/\varphi I^2 \quad \text{(A5)}$$

It is obvious that $k^*<0$ since $c<1$. This implies that the optimal access price is lower than the marginal cost of providing the access. Considering this optimal value of $k$, the access price is given by $w=2c-\beta I-1$. Therefore, the retail price equals the marginal cost of providing the access ($p=c$), the incumbent is not active in the market ($q_1=0$) and the entrant produces the whole output ($q_2=1+\beta I-c$). Since the incumbent's profits are negative, which are offset by the positive profits of the entrant, the optimal investment policy for the incumbent is to avoid any NGA deployment (i.e. $I=0$ given that $I\geq 0$).

However, it should be noted that since it is assumed that $w\geq c$, the regulator maximizes social welfare by setting $k^*=0$, or equivalently, $w=c$.

### *A2. Proof that $\varphi>\varphi_L$ is a necessary and sufficient condition to ensure that $X,Y>0$.*

Recall that $X\equiv 18\varphi+5\alpha\varphi^2-4\beta^2-10\alpha\beta\varphi$ and $Y\equiv 36\varphi+\alpha\varphi^2+4\alpha\beta\varphi-32\beta^2$. Therefore, $X=Y$ when:

$$\varphi_1=\left(9+7\alpha\beta-\sqrt{49\alpha^2\beta^2-112\alpha\beta^2+126\alpha\beta+81}\right)/(4\alpha) \quad \text{(A6)}$$

or

$$\varphi_2=\left(9+7\alpha\beta+\sqrt{49\alpha^2\beta^2-112\alpha\beta^2+126\alpha\beta+81}\right)/(4\alpha) \quad \text{(A7)}$$

In particular, $Y > X$ when $\varphi_1 < \varphi < \varphi_2$ and $X > Y$ when $\varphi < \varphi_1$ or $\varphi > \varphi_2$. In the former case ($Y > X$), $X$ and $Y$ are both positive if $X > 0$. This implies that $\varphi$ should be higher than the positive root of $X = 0$ with respect to $\varphi$ which is given by:

$$\varphi_3 = \left(5\alpha\beta - 9 + \sqrt{25\alpha^2\beta^2 + 20\alpha\beta^2 - 90\alpha\beta + 81}\right) / \left(5\alpha\right) \quad \text{(A8)}$$

However, note that the difference $\varphi_1 - \varphi_3$ is always positive for $\beta > 0$. This implies that $\varphi_1 > \varphi_3$, and hence, $\varphi > \varphi_3$ since $\varphi_1 < \varphi < \varphi_2$. As a result $X, Y > 0$.

On the contrary, $X > Y$ when $\varphi < \varphi_1$ or $\varphi > \varphi_2$. In this case, $X$ and $Y$ are both positive if $Y > 0$. This implies that $\varphi$ should be higher than the positive root of $Y = 0$ with respect to $\varphi$ which is given by:

$$\varphi_4 = \left(2\sqrt{\alpha^2\beta^2 + 8\alpha\beta^2 + 18\alpha\beta + 81} - 2\alpha\beta - 18\right) / \alpha \quad \text{(A9)}$$

It should be also noted that the difference $\varphi_1 - \varphi_4$ is always positive for $\beta > 0$. This implies that $\varphi_4 < \varphi_1$. Therefore, the condition which ensures that $Y > 0$ is $\varphi > \varphi_4$.

In conclusion, $\varphi > \varphi_4 \equiv \varphi_L$, which implies that the investment cost parameter is higher than a critical value of $\varphi$ denoted by $\varphi_L$, is a necessary and sufficient condition which ensures that $X, Y > 0$.

### *A3. The impact of $\beta$ and $\varphi$ on $\tilde{\alpha}$.*

Taking the first order condition of $\tilde{\alpha}$ with respect to $\beta$ gives:

$$\partial\tilde{\alpha} / \partial\beta = 0 \Rightarrow \varphi_\beta = \left(13\beta^2 + 36\beta - \beta\sqrt{169\beta^2 - 576\beta + 1296}\right) / 27 \quad \text{(A10)}$$

Therefore, as long as $\varphi > \varphi_\beta$, there is a positive relationship between $\tilde{\alpha}$ and $\beta$. Substituting $\varphi_\beta$ into $\tilde{\alpha}$ and then the derived value of $\tilde{\alpha}$ into $\varphi_L$, gives the lower value of $\varphi$ which ensures that $X, Y > 0$. It is proven that $\varphi_\beta = \varphi_L$, and hence $\partial\tilde{\alpha} / \partial\beta > 0$ since $\varphi > \varphi_L$. The numerical simulations presented in Appendix B and graphically illustrated in Fig. 1 verify the positive relationship between $\tilde{\alpha}$ and $\beta$.

In addition, taking the first order derivative of $\tilde{\alpha}$ with respect to $\varphi$ gives:

$$\frac{\partial\tilde{\alpha}}{\partial\varphi} = \begin{pmatrix} 18\varphi\sqrt{\psi} - 288\beta\varphi^2 + 756\beta^2\varphi - 546\beta^3\varphi - 28\beta^2\sqrt{\psi} + \\ 394\beta^4 + 324\varphi^2 + 169\beta^2\varphi^2 + 13\beta\varphi\sqrt{\psi} \end{pmatrix} / \left(5\varphi^3\sqrt{\psi}\right) \quad \text{(A11)}$$

where $\psi = 194\beta^4 - 364\beta^3\varphi + 169\beta^2\varphi^2 + 504\beta^2\varphi - 288\beta\varphi^2 + 324\varphi^2$. The numerical simulations presented in Appendix B and graphically illustrated in Fig. 1 show that there is a negative relationship between $\tilde{\alpha}$ and $\varphi$ (i.e. $\partial\tilde{\alpha} / \partial\varphi < 0$).

### *A4. The relationship between $\tilde{\varphi}$ and $\beta$.*

Taking the first order derivative of $\tilde{\varphi}$ with respect to $\beta$ provides:

$$\frac{\partial \tilde{\varphi}}{\partial \beta} = \left( \frac{33\beta - 48 + 13\sqrt{11\beta^2 - 32\beta + 36}}{5\sqrt{11\beta^2 - 32\beta + 36}} \right) \tag{A12}$$

It is easy to prove (i.e. using excel solver) that Eq. (A12) is minimized for $\beta = 0$. Therefore, for $\beta > 0$, there is a positive relationship between $\tilde{\varphi}$ and $\beta$. In addition, taking the second order derivative of $\tilde{\varphi}$ with respect to $\beta$ provides:

$$\frac{\partial^2 \tilde{\varphi}}{\partial \beta^2} = \frac{168}{\left(11\beta^2 - 32\beta + 36\right)^{\frac{3}{2}}} \tag{A13}$$

It is obvious that the second order derivative of $\tilde{\varphi}$ with respect to $\beta$ is positive since $11\beta^2 - 32\beta + 36 > 0$ due to Eq. (A12). Therefore, the critical value $\tilde{\varphi}$, which makes the incumbent undertake the socially optimal investments when $\tilde{\alpha} = 1$, increases with an increasing rate as $\beta$ increases as well.

## Appendix B

This section uses numerical simulations in order to assess the impact of regulatory uncertainty on the incumbent's incentives to undertake the socially optimal investment level. In particular, the positive value of $\alpha$, denoted by $\tilde{\alpha}$, that induces the incumbent to undertake the socially optimal investments (i.e. results in $Z = 0$) is derived for many combinations of $\beta$ and $\varphi$ under the assumptions that: (i) $\varphi < 16\beta / \tilde{\alpha}$, which implies that the investment cost parameter is not extremely high in relation to the impact of investments on demand; and (ii) $\varphi > \varphi_L(\tilde{\alpha})$, which ensures that $I^*(\tilde{\alpha}) > 0$ and $I^{**}(\tilde{\alpha}) > 0$.

In addition, the analysis is limited to the cases in which $\beta < 2$ in order to ensure that the entrant is always active in the retail market. In particular, substituting $I^*$ into Eq. (13) gives $q_2^{FC} = \varphi(1-c)(18 - 4\beta - 5\alpha\beta)/(3X)$. This implies that when the regulator compensates the incumbent for the investment risks, the entrant is active in the market when $(18 - 4\beta - 5\alpha\beta) > 0$. Obviously, $q_2^{FC} > 0$ if $\alpha < (18 - 4\beta)/(5\beta)$. However, $q_2^{FC}$ decreases with an increase in $\alpha$. Therefore, if $q_2^{FC} > 0$ when $\alpha = 1$, then $q_2^{FC} > 0$ for $\alpha \in [0,1]$. The condition which ensures that $q_2^{FC} > 0$ when $\alpha = 1$ is $\beta < 2$. Therefore, although a necessary and sufficient condition to ensure that $q_2^{FC} > 0$ is $(18 - 4\beta - 5\alpha\beta) > 0$, the condition $\beta < 2$ can be used for simplicity without affecting the final results.

Tables B1-B3 provide the positive and the negative values of $\alpha$, which are denoted respectively by $\tilde{\alpha}$ and $\tilde{\alpha}_2$, and lead the incumbent to undertake the socially optimal investments. The derive results corresponds to the cases in which the investment cost parameter takes positive integral values between 1 and 10, whereas the impact of investment on demand is $\beta = 0.5$, $\beta = 1$ or $\beta = 1.5$. It is found that regardless of the particular value of $\beta$, $\tilde{\alpha}$ is always positive and

$\tilde{\alpha}_2$ is always negative. In addition, $\tilde{\alpha}$ is positively correlated with $\beta$ and negatively correlated with $\varphi$. These results numerically verify the respective results of Appendix A3. Moreover, an increase in $\varphi$ leads $\tilde{\alpha}$ to decrease and $\tilde{\alpha}_2$ to increase. Simulations show that when $\varphi$ tends to infinity, then $\tilde{\alpha} = \tilde{\alpha}_2 = 0$. This implies that there is always one positive and one negative value of $\tilde{\alpha}$. Thus, the whole analysis is based on the positive value of $\alpha$, denoted by $\tilde{\alpha}$, which induces the incumbent to undertake the socially optimal investments. Tables B1-B3 also show the value of $\varphi$, denoted by $\varphi_L(\tilde{\alpha})$, which ensure that when $\alpha = \tilde{\alpha}$, the privately and the socially optimal investment levels are both positive. The derived levels of investments and social welfare are also provided for $\varphi > \varphi_L(\tilde{\alpha})$.

**Table B1** ($\beta = 0.5$, $c = 0.5$)

| $\boldsymbol{\varphi}$ | $\tilde{\boldsymbol{\alpha}}$ | $\tilde{\boldsymbol{\alpha}}_2 < \mathbf{0}$ | $\boldsymbol{\varphi}_L(\tilde{\boldsymbol{\alpha}})$ | $\boldsymbol{I}^*(\tilde{\boldsymbol{\alpha}}) = \boldsymbol{I}^{**}(\tilde{\boldsymbol{\alpha}})$ | $\boldsymbol{SW}^*(\tilde{\boldsymbol{\alpha}}) = \boldsymbol{SW}^{**}(\tilde{\boldsymbol{\alpha}})$ |
|---|---|---|---|---|---|
| **1** | 1.099 | -13.099 | 0.208 | 0.220 | 0.132 |
| **2** | 0.609 | -5.909 | 0.214 | 0.098 | 0.120 |
| **3** | 0.421 | -3.799 | 0.217 | 0.063 | 0.117 |
| **4** | 0.322 | -2.797 | 0.218 | 0.047 | 0.115 |
| **5** | 0.260 | -2.212 | 0.219 | 0.037 | 0.115 |
| **6** | 0.219 | -1.830 | 0.219 | 0.031 | 0.114 |
| **7** | 0.188 | -1.560 | 0.220 | 0.026 | 0.114 |
| **8** | 0.166 | -1.359 | 0.220 | 0.023 | 0.113 |
| **9** | 0.148 | -1.209 | 0.220 | 0.020 | 0.113 |
| **10** | 0.133 | -1.081 | 0.220 | 0.028 | 0.113 |

**Table B2** ($\beta = 1$, $c = 0.5$)

| $\boldsymbol{\varphi}$ | $\tilde{\boldsymbol{\alpha}}$ | $\tilde{\boldsymbol{\alpha}}_2 < \mathbf{0}$ | $\boldsymbol{\varphi}_L$ | $\boldsymbol{I}^*(\tilde{\boldsymbol{\alpha}}) = \boldsymbol{I}^{**}(\tilde{\boldsymbol{\alpha}})$ | $\boldsymbol{SW}^*(\tilde{\boldsymbol{\alpha}}) = \boldsymbol{SW}^{**}(\tilde{\boldsymbol{\alpha}})$ |
|---|---|---|---|---|---|
| **1** | 1.704 | -16.904 | 0.726 | 1.142 | 0.338 |
| **2** | 1.200 | -6.000 | 0.767 | 0.250 | 0.158 |
| **3** | 0.916 | -3.494 | 0.792 | 0.133 | 0.137 |
| **4** | 0.738 | -2.428 | 0.809 | 0.096 | 0.129 |
| **5** | 0.618 | -1.860 | 0.821 | 0.072 | 0.124 |
| **6** | 0.530 | -1.508 | 0.830 | 0.059 | 0.122 |
| **7** | 0.465 | -1.265 | 0.837 | 0.050 | 0.120 |
| **8** | 0.417 | -1.088 | 0.842 | 0.043 | 0.119 |
| **9** | 0.372 | -0.955 | 0.846 | 0.038 | 0.118 |
| **10** | 0.339 | -0.851 | 0.850 | 0.034 | 0.117 |

**Table B3** ($\beta = 1.5$, $c = 0.5$)

| $\varphi$ | $\tilde{\alpha}$ | $\tilde{\alpha}_2 < 0$ | $\varphi_L$ | $I^*(\tilde{\alpha}) = I^{**}(\tilde{\alpha})$ | $SW^*(\tilde{\alpha}) = SW^{**}(\tilde{\alpha})$ |
|---|---|---|---|---|---|
| **1** | 1.682 | -25.622 | 1.482 | - | - |
| **2** | 1.500 | -7.200 | 1.523 | 0.875 | 0.366 |
| **3** | 1.298 | -3.698 | 1.571 | 0.283 | 0.190 |
| **4** | 1.125 | -2.400 | 1.616 | 0.167 | 0.156 |
| **5** | 0.985 | -1.753 | 1.654 | 0.118 | 0.142 |
| **6** | 0.874 | -1.374 | 1.686 | 0.091 | 0.135 |
| **7** | 0.783 | -1.126 | 1.713 | 0.074 | 0.130 |
| **8** | 0.709 | -0.952 | 1.736 | 0.062 | 0.127 |
| **9** | 0.647 | -0.825 | 1.755 | 0.054 | 0.125 |
| **10** | 0.595 | -0.727 | 1.772 | 0.047 | 0.123 |

It should be noted that for $\tilde{\alpha} \in [0,1]$ the optimal investment level is lower than 1. This result leads to access prices which are higher than the total investment costs, and hence, the condition that $k < 1$ is violated. However, this result is due to the normalized demand function used in this paper. It is easy to proof that an inverse demand function given (for example) by $p = 100 + \beta I - (q_1 + q_2)$, which implies that this demand curve intersects the price axis at a significantly higher point than $p = 1 + \beta I - (q_1 + q_2)$, results in $k < 1$ without affecting the derived outcomes concerning the particular values of $\tilde{\alpha}$.

Table B4 presents the corresponding results when $\beta = 2$. In this case the value of $\alpha$ should be lower that 1 in order to ensure that $q_2^{FC} > 0$. It is found that $\tilde{\alpha} < 1$ for $\varphi > 8$. In addition, when $\beta = 2.5$, $\tilde{\alpha} \leq 1$ for $\varphi \geq 21.25$. This implies that as $\beta$ increases, the level of the investment cost parameter which ensures that $q_2^{FC} > 0$ increases with an increasing rate.

**Table B4** ($\beta = 2$, $c = 0.5$)

| $\varphi$ | $\tilde{\alpha}$ | $\tilde{\alpha}_2 < 0$ | $\varphi_L$ | $I^*(\tilde{\alpha}) = I^{**}(\tilde{\alpha})$ | $SW^*(\tilde{\alpha}) = SW^{**}(\tilde{\alpha})$ |
|---|---|---|---|---|---|
| **9** | 0.926 | -0.768 | 2.783 | 0.070 | 0.134 |
| **10** | 0.861 | -0.669 | 2.824 | 0.060 | 0.131 |

Lastly, Table B5 shows the values of $\tilde{\varphi}$ that makes the privately and the socially optimal investment levels coincide when $\tilde{\alpha} = 1$.

**Table B5** ($c = 0.5$)

| $\boldsymbol{\beta}$ | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 |
|---|---|---|---|---|---|---|
| $\tilde{\boldsymbol{\varphi}}$ | 1.124 | 2.648 | 4.885 | 8 | 11.770 | 15.894 |
| $\tilde{\boldsymbol{\varphi}}_2$ | -10.324 | -6.648 | -3.685 | -1.6 | -0.170 | 0.906 |

It is obvious that as long as $\beta \leq 2.5$, the highest value of $\varphi$ that makes the privately and the socially optimal investment levels coincide when $\tilde{\alpha} = 1$ is denoted by $\tilde{\varphi}$ since $\tilde{\varphi} > 0$ and $\tilde{\varphi}_2 < 0$. Therefore, if $\varphi < \tilde{\varphi}$ (respectively, $\varphi > \tilde{\varphi}$), the value of $\alpha$ that makes the incumbent undertake the socially optimal investments is higher (respectively, lower) than 1. However, note that when $\beta = 2$, the value of $\tilde{\varphi}$ is equal to the respective value of $\varphi$ that makes $q_2^{FC} = 0$. Therefore, $\varphi > \tilde{\varphi}$, and hence, $\tilde{\alpha} < 1$. In addition, when $\beta \geq 3$, $\tilde{\varphi}$ and $\tilde{\varphi}_2$ are both positive. However, note that in such cases the value of $\varphi$ should be extremely high in order to ensure that $q_2^{FC} > 0$. For example, when $\beta = 3$, the investment cost parameter which ensure that $q_2^{FC} > 0$ is $\varphi > 48$. Therefore, $\varphi$ should be higher than the highest value of $\varphi$ that makes the privately and the socially optimal investment levels coincide when $\tilde{\alpha} = 1$. As a result, $\varphi > \tilde{\varphi}$, which implies that $\tilde{\alpha} < 1$. From the above analysis, it is proven that $\tilde{\varphi}_2$ does not affect the final outcomes, and hence, the whole analysis should focus on $\tilde{\varphi}$.

Furthermore, Table B5 numerically verifies the results of Appendix A4 concerning the relationship between $\beta$ and $\tilde{\varphi}$. In particular, the critical value $\tilde{\varphi}$ increases with an increasing rate as $\beta$ increases as well. In addition, Table B5 is in line with Fig. 1 since it reveals the values of $\varphi$ that make $\tilde{\alpha} = 1$ for different values of $\beta$.

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# NGA Investment Incentives under Geographic Price Discrimination

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ABSTRACT

This paper compares the impact of retail price discrimination and uniform pricing on a monopolist's incentives to extend its Next Generation Access (NGA) network deployment to less densely populated geographic areas. It is found that geographic price discrimination provides the monopolist with higher incentives to deploy a larger NGA network. In addition, geographic price discrimination results in better welfare outcomes than uniform pricing as long as the investment cost is not extremely low. In such cases, the regulator should allow the monopolist to geographically price discriminate since the monopolist chooses the socially optimal pricing regime.

**Keywords:** geographic markets, investment incentives, next generation access networks, price discrimination, social welfare

**JEL classification:** L43, L51, L96

## 1. Introduction

During the last decade, the number of internet users, as well as, the capacity they demand have increased spectacularly. As a result, the increasing transmitted volume of data has made the traditional access copper networks incapable of providing end-users with the demanded bandwidth. On the contrary, access networks based on optical fibre are the only future proof solution capable to satisfy the future demand (Shumate, 2008) since the transmission capabilities of fibre are theoretically unlimited providing high data rates, low loss and low distortion. Such fibre-based access networks are widely known as Next Generation Access (NGA) networks.

Not only technical reasons but also economic ones make the need for investments in NGA networks imperative. In particular, it is found that investments in broadband infrastructures have an undisputable positive effect on economic growth, broadband diffusion and job creation (Czernich et al., 2011; ITU, 2012). These results partially interpret why national governments rank among their top priorities the encouragement of investments in NGA networks.

Nevertheless, a number of features of NGA networks make investments principally challenging. Demand uncertainty is particularly problematic because of the substantial sunk investment cost. In addition, there has been an ongoing discussion on the outcomes of potential regulatory intervention, especially with regard to its impact on investment and competition outcomes. According to several studies (Charalampopoulos et al., 2011; Nitsche and Wiethaus, 2011), permanent or temporary absence of access regulation (regulatory forbearance or holidays, respectively) appear superior to other regulatory regimes in terms of both NGA investment level and the timing of investments, although they result in ambiguous outcomes in terms of social welfare.

Recently, there has also been a growing discussion supporting regulatory forbearance in certain geographic areas as a means of stimulating NGA investments (ERG, 2008). This could lead to geographic de-averaging of prices that would reflect the geographic variances in market conditions, which may significantly differ from traditional PSTN/DSL conditions. Indeed, after a period of obligation of non-discrimination (EU, 2002), currently, price discrimination is allowed to a certain (at least wholesale) extent related to NGA networks in Europe in order to foster innovation and welfare growth by promoting investments (EC, 2010). Thus, there may be a case for designing remedies that can vary across geographic markets that would be defined as locations with e.g., homogeneity in willingness to pay, competitive conditions, cost, etc. Such practice is widely known as price discrimination which can be defined as selling the same product to different customers at different prices even if the cost of sale is the same to each other (Posner, 2001).

Concerning the prospective consumers' reaction to the launch of NGA-based services, it is expected that there will be a significant variation among consumers' willingness to pay for the additional benefits of such enhanced services. This implies that some end-users, which have low willingness to pay, will still buy the basic "universal-level" service only, while some others have higher valuation for advanced bandwidth-hungry services, and hence, will migrate to the NGA networks. The main take-away of the relevant studies (Flamm and Chaudhuri, 2007; Preston et al., 2007) is that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) densely populated areas. Under a geographic price discrimination perspective the operator could exploit such information and be able to price-discriminate in order to reflect more closely retail consumers' willingness to pay ("value-based" pricing) and/or geographical differences in network costs.

Academic research points out that price discrimination increases producer surplus while the outcomes on consumer surplus and social welfare are heterogeneous. Varian (1985) shows that a necessary condition for price discrimination to improve welfare is that output increases. More recent articles study the impact of price discrimination not only on welfare outcomes, but also on a monopolist's investment incentives. In particular, these recent articles study the impact of price discrimination on the level of investment in quality (Alexandrov and Deb, 2012; Valletti, 2006). In both articles the number of the markets that the quality-enhanced product will be sold is exogenously defined, whereas the investment in quality is endogenously derived. It is found that price discrimination results in more investment in quality than uniform pricing, whereas its impact on social welfare depends on the specific underlying industry characteristics.

Contrary to the above-mentioned articles, this paper studies the impact of price discrimination on the geographic level of NGA deployment chosen by a monopolist. This implies that the quality of an NGA-based service is exogenously defined (e.g., FTTH), whereas the number of geographic areas (markets) that this service will be provided is endogenously chosen. It is found that that geographic price discrimination provides the monopolist with higher incentives to deploy a larger NGA network. In addition, geographic price discrimination results in better welfare outcomes than uniform pricing as long as the investment cost is not extremely low. The policy implication from these results is that an unregulated monopolist will choose the socially optimal pricing regime as long as the investment cost is not extremely low.

The rest of the paper is as follows. Section 2 presents the model. Section 3 compares two pricing regimes, differential and uniform pricing, in terms of investment incentives and the subsequent social welfare level. The last section summarizes the main results of this article and proposes the directions for future work.

## 2. The model

Assume a hypothetical country consisting of different geographic areas which can be indexed in a decreasing order according to their population density. In particular, geographic areas are indexed by $i$ with $i \in [1, n]$, where low values of $i$ imply geographic areas with high population density, whereas geographic areas that are indexed by $i$ close to $n$ represent rural areas (i.e., with low population density). A monopolist provides a basic "universal-level" broadband service (e.g., ADSL) to all geographic areas at a uniform price.

Now assume that the monopolist invests in access network upgrade in order to provide a certain ultra-fast NGA-based service to the consumers (i.e., FTTH). The monopolist determines the geographic extent of the NGA deployment denoted by $x \in [1, n]$. A larger $x$ reflects a fibre deployment to less densely populated geographic areas. The monopolist faces a quadratic NGA investment cost with respect to $x$, given by $c(x) = \varphi x^2 / 2$. The parameter $\varphi > 0$ represents the slope of the marginal investment cost function, and hence, higher values of $\varphi$ imply a higher investment cost for a given investment level. The convex form reflects the fact that fibre deployment becomes marginally more expensive as it is extended to rural, less densely populated areas. It is further assumed that the NGA investment level does not have any impact on the marginal cost of providing the NGA-based service. Thus, the unit costs of production and distribution are set to zero.

In addition, the NGA deployment positively affects the willingness to pay of all consumers e.g., due to the emerging positive network effects. However, as it has already been noted in the introduction section, the consumers who live in more densely populated areas place a higher valuation to the additional benefits stemming from the NGA-based services than the consumers who live in less densely populated areas. In particular, it is assumed that the impact of the NGA deployment on the consumers' willingness to pay is given by $(x/i^2)$. Therefore, the demand function in each geographic area $i$ is given by:

$$q_i = A + x / i^2 - p_i \tag{1}$$

where $p_i$ and $q_i$ are the retail market price and the quantity supplied by the monopolist, respectively, in each geographic area. The parameter $A$ represents the point at which the inverse demand function, $p_i = A + x / i^2 - q_i$, intersects the vertical (price) axis when no investments have taken place. This implies that $A$ represents the maximum valuation that the consumers place to the basic "universal-level" service, which affects the overall valuation for this service. As a result, the profit function of the monopolist in each geographic area is given by:

$$\Pi_i = p_i(A + x / i^2 - p_i) \tag{2}$$

whereas, the total profits of the monopolist are given by:

$$\Pi = \int_1^x p_i(A + x / i^2 - p_i)di - (\varphi x^2 / 2) \tag{3}$$

A two-stage game is considered. In the first stage, the monopolist determines the extent of the NGA deployment, whereas in the second stage, it provides the exogenously determined quality of the NGA-based service in the geographic areas where the NGA network has been deployed and sets the price(s) according to the chosen pricing regime. In particular, there are two possible pricing regimes. Under the first pricing regime, the monopolist sets a different retail price to each geographic area (differential pricing) which reflects the different impact of the NGA deployment on the willingness to pay of the consumers who live in different geographic areas. According to the second one, the monopolist sets the same retail price (uniform pricing) to all geographic areas.

## 3. Investment and welfare outcomes

This section compares the two pricing regimes in terms of investment incentives and social welfare. In both cases, the game is solved backwards. This implies that in the second stage, the investment cost is sunk and the monopolist sets the price(s) of the ultra-fast broadband service for a given level of NGA deployment chosen in the first stage.

### *3.1. Differential pricing*

In each geographic area, the monopolist sets the retail price that maximizes its profits. Taking the first order condition of (2) with respect to $p_i$ yields the optimal regional retail prices as a function of the investment level $x$:

$$p_i = \frac{A}{2} + \frac{x}{2i^2} \tag{4}$$

Substituting (4) into (1) gives the quantity demanded (number of subscribers) in each geographic area:

$$q_i = \frac{A}{2} + \frac{x}{2i^2} \tag{5}$$

Therefore, the total profits of the monopolist and the consumer surplus are given, respectively, by:

$$\Pi^d = \int_1^x \left(\frac{A}{2} + \frac{x}{2i^2}\right)^2 di - \frac{\varphi x^2}{2} = (x-1)(3A^2x + 6Ax + x^2 + x + 1)/(12x) - (\varphi x^2/2) \tag{6}$$

$$CS^d = \int_1^x \frac{q_i^{\,2}}{2} di = (x-1)(3A^2x + 6Ax + x^2 + x + 1)/(24x) \tag{7}$$

Taking the first order condition of (6) with respect to $x$ gives the optimal investment level chosen by the monopolist under price discrimination:

$$x^d = \frac{y}{3z} + v + \frac{y^2}{9z^2 v} \tag{8}$$

where:

$$y = 3A^2 + 6A \tag{9}$$

$$z = 12\varphi - 2 \tag{10}$$

$$v = \left\{ \sqrt{\left[\left(\frac{y}{3z}\right)^3 + \frac{1}{2z}\right]^2 - \left(\frac{y}{3z}\right)^6} + \left(\frac{y}{3z}\right)^3 + \frac{1}{2z} \right\}^{1/3} \tag{11}$$

This investment level reflects the less densely populated geographic area which is passed by NGA network. Substituting (8) into (6) gives the monopolist's profits from all NGA geographic areas passed ($\Pi^d$), whereas consumer surplus ($CS^d$) is derived by substituting (8) into (7). Social welfare ($W^d$) is the unweighted sum of profits and consumer surplus.

### *3.2. Uniform pricing*

In this pricing regime, the monopolist sets the same price, $p$, in each geographic area. This implies that the demand function in each geographic area $i$ is $q_i = A + x/i^2 - p$, and hence, the total demand faced by the monopolist is given by:

$$q = \int_1^x q_i \, di = (x-1)(A+1-p) \tag{12}$$

Therefore, the total profits of the monopolist are given by:

$$\Pi^u = pq - (\varphi x^2/2) = p(x-1)(A+1-p) - (\varphi x^2/2) \tag{13}$$

Taking the first order condition of (13) with respect to $p$ yields the optimal retail price:

$$p = (A+1)/2 \tag{14}$$

As a result, the total quantity demanded (number of subscribers) in all geographic areas is given by:

$$q = (x-1)(A+1)/2 \tag{15}$$

Therefore, the total profits of the monopolist and the consumer surplus are given, respectively, by:

$$\Pi^u = (x-1)(A+1)^2/4 - (\varphi x^2/2) \tag{16}$$

$$CS^u = \int_1^x \frac{q_i^{\,2}}{2} di = (x-1)(3A^2x + 6Ax + 4x^2 - 5x + 4)/(24x) \tag{17}$$

Taking the first order condition of (16) with respect to $x$ yields the optimal investment level chosen by the monopolist under uniform pricing:

$$x^u = \frac{(A+1)^2}{4\varphi} \tag{18}$$

Substituting (18) into (16) gives the monopolist's profits from all NGA geographic areas passed ($\Pi^u$), whereas consumer surplus ($CS^u$) is derived by substituting (18) into (17). Social welfare ($W^u$) is the unweighted sum of profits and consumer surplus.

### *3.3. Comparison of the pricing regimes*

This section compares the two pricing regimes in terms of investment incentives and social welfare. It is obvious that the complex form of (8), which gives the optimal investment level under differential pricing, makes the comparison of the investment levels derived by differential and uniform pricing extremely difficult without providing much critical appraisal. In addition, both the monopolist's profits and consumer surplus are significantly affected by the chosen investment levels, and hence, the comparison of the social welfare levels under each pricing regime is also extremely difficult in a theoretical way. Thus, numerical simulations are used in order to compare the two pricing regimes in terms of investment incentives and social welfare.

There are two independent parameters, $A$ and $\varphi$. Therefore, this paper studies the impact of such parameters on the effectiveness of each pricing regime to induce higher levels of both investments and social welfare. It is obvious that the study focuses on the range of the parameters that leads to non-negative profits for the monopolist under both regimes. In particular, differential pricing leads to non-negative profits for $\underline{\varphi}^d \le \varphi \le \overline{\varphi}^d$, whereas, under uniform pricing, the monopolist's profits are non-negative for $\varphi \leq \overline{\varphi}^{u}$. These critical values of $\varphi$ are affected by a change in $A$ according to the following Table.

**Table 1.** The critical values of $\varphi$ for different values of $A$

| A | $\underline{\varphi}^{d}$ | $\overline{\varphi}^{d}$ | $\overline{\varphi}^{u}$ | $\varphi^{x}$ | $\varphi^{W}$ |
|---|---|---|---|---|---|
| 5 | 0.605 | 8.469 | 4.500 | 9.045 | 0.878 |
| 10 | 0.589 | 29.740 | 15.125 | 30.424 | 0.868 |
| 15 | 0.586 | 63.490 | 32.000 | 63.071 | 0.866 |
| 20 | 0.584 | 109.740 | 55.125 | 110.865 | 0.865 |
| 25 | 0.584 | 168.490 | 84.500 | 172.419 | 0.865 |
| 30 | 0.584 | 239.740 | 120.125 | 236.401 | 0.865 |

It is obvious that $\overline{\varphi}^{u} < \overline{\varphi}^{d}$ for all values of $A$, and hence, the range that leads the monopolist to earn non-negative profits under both pricing regimes is $\underline{\varphi}^{d} \leq \varphi \leq \overline{\varphi}^{u}$. Figure 1 shows the impact of $A$ and $\varphi$ on the investment levels undertaken by the monopolist under each pricing regime for $A=5$, $A=10$, $A=15$ and $A=20$.

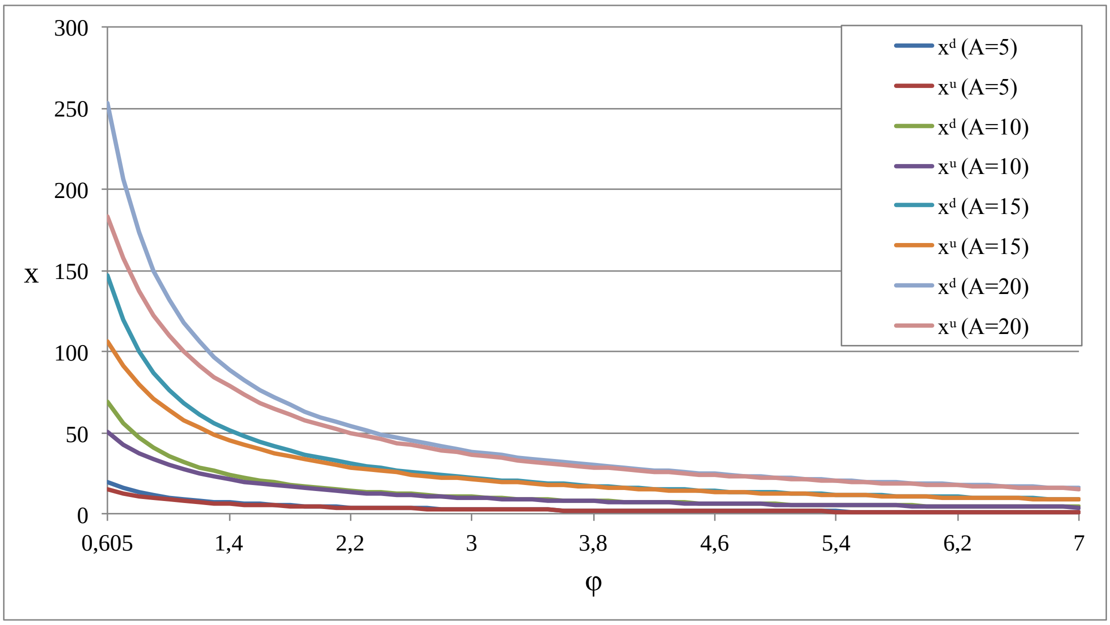


**Figure 1.** The levels of NGA deployment under differential and uniform pricing as a function of $\varphi$ for different values of $A$

From figure 1 it can be deduced that for any given value of $A$, an increase in $\varphi$ leads the monopolist to undertake a lower NGA deployment either under differential or uniform pricing regime. This implies that as the investment cost increases, the monopolist has lower incentives to invest in NGA networks. In addition, an increase in $A$ shifts the investment function upwards, which implies that, given a particular investment cost parameter $\varphi$, higher valuation for the basic "universal-level" broadband service leads to higher investment levels. It is thus obvious that an increase in $\varphi$ negatively affects both investment levels, whereas an increase in $A$ positively affects the monopolist's investment incentives. Not surprisingly, the monopolist has higher incentives to deploy a larger NGA network for low investment cost and high valuation for the basic "universal-level" broadband service.

Concerning the impact of $A$ and $\varphi$ on the effectiveness of each pricing regime to induce higher investment level, simulations show that differential pricing leads to higher investment level than uniform pricing as long as $\varphi \neq \varphi^x$. When $\varphi = \varphi^x$, the two pricing regimes result in the same outcome in terms of NGA deployment (i.e., $x^d = x^u$). Table 1 also provides the values of $\varphi^x$ for different values of $A$. It is obvious that $\varphi^x$ is always higher than the upper limit of $\varphi$ (denoted by $\overline{\varphi}^u$) that makes the monopolist earn non-negative profits under both pricing regime. Therefore, the following proposition can be stated:

**Proposition 1.** *For any admissible values of $A$ and $\varphi$, differential pricing always results in higher investment levels than uniform pricing (i.e., $x^d > x^u$).*

The main regulatory implication stemming from the above proposition is that the regulator should allow the monopolist to geographically price discriminate if its unique purpose is to promote investments in NGA networks. However, the goal of regulators is not only to encourage NGA investments but also to prevent the monopolist from exploiting its market power to the detriment of consumers. In other words, the regulator should allow the monopolist to geographically price discriminate if such regime results in better outcomes than uniform pricing in terms of both investment incentives and social welfare. Figure 2 shows the impact of $A$ and $\varphi$ on the subsequent social welfare levels derived by the monopolist's optimal investment choice under each pricing regime for $A=5$, $A=10$, $A=15$ and $A=20$.

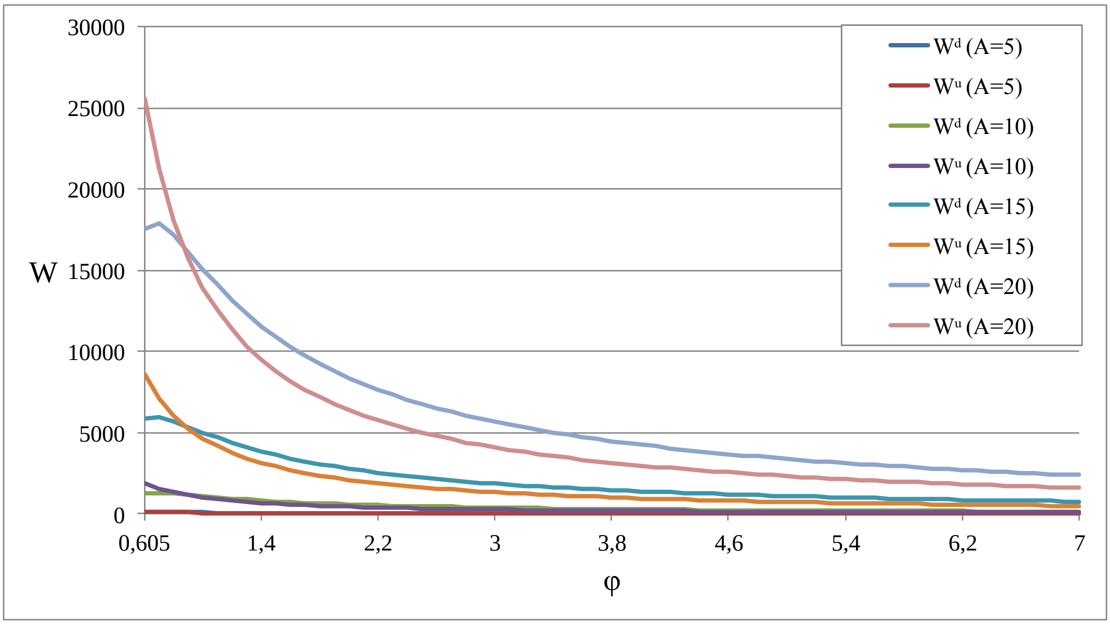


**Figure 2.** The levels of social welfare under differential and uniform pricing as a function of $\varphi$ for different values of $A$

It is obvious that the behavior of the welfare functions is similar to that of investments. In particular, an increase in $A$ has a positive impact on the welfare levels derived by both pricing regimes, whereas an increase in the investment cost $\varphi$ negatively affects the social welfare outcomes. Concerning the comparison between the derived social welfare levels under each pricing regime, simulations show that differential pricing leads to better welfare outcomes than uniform pricing as long as $\varphi > \varphi^W$. On the contrary, when $\varphi < \varphi^W$, the socially optimal pricing regime is that of uniform pricing. Therefore, for every value of $A$, there is a critical value of $\varphi$ denoted by $\varphi^W$ that makes $W^d = W^u$. This fact is clearly depicted in figure 2, whereas Table 1 provides the particular values of $\varphi^W$ for different values of $A$.

Note that the values of $\varphi^W$ are very close to that of $\underline{\varphi}^d$ implying that there is a very limited range of $\varphi$ that makes $W^u > W^d$ hold. In other words, when $\underline{\varphi}^d \leq \varphi < \varphi^W$, uniform pricing is the socially optimal pricing regime. In this case, there is a trade-off between encouraging the monopolist to deploy a larger NGA network and preventing the monopolist from exploiting its market power. However, when $\varphi > \varphi^W$, differential pricing leads to better outcomes than uniform pricing in terms of both investments and social welfare. Given that the particular value of $\varphi^W$ is rather low and the range of $\varphi$ that makes $W^u > W^d$ hold is rather limited, the following proposition can be stated:

**Proposition 2.** *The regulator should allow the monopolist to geographically price discriminate as long as the investment cost is not extremely low.*

As a result, geographic price discrimination in NGA markets should be allowed by the regulator when the investment cost is not extremely low. In this case, the monopolist will price the NGA-based services according to the socially optimal pricing regime, which is the differential pricing. On the contrary, when the investment cost is extremely low (i.e., $\underline{\varphi}^d \leq \varphi < \varphi^W$), there is a trade-off between encouraging investments and promoting social welfare. In this case, the regulator may oblige a uniform pricing in order to improve social welfare since investments in access infrastructures may have already been encouraged by allowing the monopolist to ban access to the new NGA infrastructures by alternative operators (these are the cases of regulatory forbearance or regulatory holidays).

## 4. Conclusions

This paper discussed the impact of retail price discrimination on investment incentives and social welfare when the investor is not obliged to provide access to its improved access infrastructures to its competitors. In particular, it was assumed that the firm invests in NGA networks under regulatory forbearance or regulatory holiday. Thus, the investor firm acts as a monopolist in the market for ultra-fast broadband services provided over the new fibre-based access network. It was further assumed that the consumers place a different valuation to the ultra-fast broadband connection according to their geographic area. In particular, consumers who live in more densely populated areas place a higher valuation to the ultra-fast broadband service due to socioeconomic characteristics, such as income, education, etc.

It was found that geographic price discrimination provides the monopolist with higher incentives to deploy a larger NGA network (i.e., the NGA investment is extended to rural, less densely populated areas). In addition, geographic price discrimination results in better welfare outcomes than uniform pricing as long as the investment cost is not extremely low. In such cases, the regulator should allow the monopolist to geographically price discriminate since the monopolist chooses the socially optimal pricing regime. On the contrary, when the investment cost is extremely low, uniform pricing is the socially optimal pricing regime, whereas differential pricing maximizes private investment incentives. In such cases, a benevolent regulator may impose the uniform pricing regime in order to mitigate the detrimental impact of regulatory forbearance or holidays on social welfare.

Although its limitations, this paper provided some very interesting results concerning the regulation of the retail NGA market. However, since the focus of regulators is continuously shifting from the regulation of the retail market to the regulation of the wholesale market, this paper can trigger a discussion on the investment and welfare outcomes of geographic price discrimination at a wholesale level. Thus, future research should focus on improving this paper by introducing competition both for investments and consumers, and then, studying the regulatory implications of a geographic differentiated access price.

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# Geographically Differentiated NGA Deployment

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**Abstract**

This paper studies the incentives of an unregulated monopolist to undertake the socially optimal investment in NGA networks when it takes into account the fact that the NGA deployment is a two-dimensional investment decision concerning both the quality (or equivalently, technology) and the geographic coverage. It is found that both the privately and the socially optimal investment decisions result in a geographically differentiated NGA deployment implying that different quality NGA networks are deployed in different geographic areas. In particular, NGA networks of higher (lower) quality are deployed in the more (less) densely populated geographic areas. Although such geographically differentiated NGA investment leads the monopolist to provide a nationwide NGA deployment, it is found that the monopolist underinvests compared to the socially optimal levels of both technology and geographic coverage. In addition, since the objectives of the Europe 2020 Strategy concern both the NGA technology and the NGA coverage, this paper shows that the first objective of providing all Europeans with access to much higher internet speeds of above 30 Mbps is feasible when the demand for NGA-based services is significantly elastic, whereas the second objective of providing internet connection speeds of 100 Mbps to 50% or more of European households is not a feasible goal.

**Keywords**: Broadband, geographic areas, investment incentives, next generation access networks, telecommunications

## 1. Introduction

Investments in Next Generation Access (NGA) networks[1], which allow ultra fast internet connections, are expected to have a positive impact on economic growth, employment and social prosperity. This fact has been notably highlighted in the European Commission Recommendation on regulated access to NGA (EC, 2010a) and in the Digital Agenda for Europe (EC, 2010b), whereas it has been empirically proven by Czernich, Falck, Kretschmer and Woessmann (2011) and Katz, Vaterlaus, Zenhäusern and Suter (2010). However, recent data from the European Commission (EC, 2012) shows that European telecommunication operators are reluctant to invest in NGA networks. According to the Dutch regulatory authority, OPTA (2008), the main factors that negatively affect an investor's incentives to invest in NGA networks are: (i) the uncertainty about future demand for new NGA-based services; and (ii) the regulatory uncertainty related to the regulator's limited ability to make *ex ante* credible commitments. Therefore, there is a growing interest among policy makers about the optimal regulatory policy that promotes both competition and investment in NGA networks.

### *1.1. Regulatory concerns*

In fact, the assessment of such optimal regulatory policy is a very complex and challenging task because there are many different factors that affect the profitability of an NGA investment project and the subsequent competition outcomes. This implies that regulators have to make a number of decisions that directly affect the level of NGA deployment and the intensity of competition.

Initially, regulators have to decide the regulatory regime applied to the NGA market. Permanent regulation implies that the *ex ante* imposed remedies hold for the whole lifecycle of the NGA investment, whereas regulatory forbearance refers to the situation where there is no *ex ante* regulation on NGA networks. Regulatory holidays and sunset clauses are intermediate regulatory regimes between regulatory forbearance and permanent regulation. Under regulatory holidays, the investor is not imposed to any regulatory constraints for a predetermined period of time, whereas by imposing a sunset clause, the regulator commits that will withdraw access obligations after a predetermined date. It is obvious that regulatory forbearance or holidays appear superior to the other regulatory regimes in terms of both NGA investment level and the timing of the investments but they fail to promote an efficient competition level (Charalampopoulos, Katsianis and Varoutas, 2011; Gavosto, Ponte and Scaglioni, 2007; Nitsche and Wiethaus, 2011).

Secondly, regulators have to assess the level of the access price that an access seeker should pay to the NGA investor in order to have access to the fibre-based access network. This regulatory decision has attracted much interest in the policy debate. A sizeable number of papers study the effect of different combinations of regulatory regimes and access prices on an operator's investment incentives and on the subsequent social welfare outcomes. A first literature strand concludes

[1] According to European Commission (EC, 2010a), Next Generation Access (NGA) networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network.

that an unbundling policy that boosts entry by alternative operators promotes static efficiency but leads to losses in dynamic efficiency (Bouckaert, van Dijk and Verboven, 2010).[2] This implies that cost-oriented access prices is an effective regulatory tool for fostering service-based competition in order to improve static efficiency, but they cannot promote investments in new NGA networks by either incumbents or entrants since the investors are not compensated for the uncertainty of NGA investment.[3]

As a result, a second literature strand studies the impact of alternative regulatory settings on promoting both static and dynamic efficiency. In particular, this set of papers explores the effectiveness of several investment-contingent access prices to increase both static and dynamic efficiency when a single operator invests under either demand uncertainty (Bender, 2011; Nitsche and Wiethaus, 2011) or regulatory uncertainty (Klumpp and Su, 2010; Sarmento and Brandao, 2007; Tselekounis and Varoutas, 2013), as well as, when two operators invest in non-overlapping areas (Henriques, 2011; Sauer, 2011). This literature concludes that compensating the investor(s) for the uncertainty of NGA investment through an investment-contingent access price can achieve both static and dynamic efficiency under certain demand, cost and regulatory conditions.

The aforementioned papers that study the impact of alternative regulatory regimes and access pricing rules on investment and competition outcomes neglect the fact that there is a period during which both copper and NGA networks are in operation and are competing for customers. Therefore, the third regulatory decision concerns the level of the access price applied to the copper access network. This regulatory task gives rise to a more recent stream of papers which discuss the impact of the regulation of the copper access network on the firms' investment incentives when the NGA market is left unregulated or when there is an interplay between the access prices of the two networks (Bourreau, Cambini and Doğan, 2013; Bourreau, Cambini and Doğan, 2012; Bourreau, Lupi and Manenti, 2013; Brito, Pereira and Vareda, 2012; Cambini and Silvestri, 2012; Cave, Fournier and Shutova, 2012; Inderst and Peitz, 2012; Neumann and Vogelsang, 2013). The main conclusion of this literature is that although a higher access charge for the copper access network seems to lead to lower incentives to invest for the firm owning the copper access network and to stronger incentives to invest for its competitor, a positive correlation between the access prices of the two networks incentivizes the migration to the NGA network.

A last regulatory decision, which has mostly been overlooked in the related literature, concerns the possibility of defining different geographical markets according to the prevailing competitive and cost conditions, and therefore, the imposition of geographically differentiated remedies. Indeed, after a period of

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[2] Static efficiency concerns the short-run regulatory goal to provide firms with significant incentives to invest in innovative, differentiated services. Such service-based competition leads to a self-sustaining pro-competitive market structure in which firms behave in a competitive manner, and hence, the consumers enjoy the welfare gains from static efficiency (lower prices, better quality and extended variety of services). On the other hand, dynamic efficiency concerns the long-run goal of access regulation to induce the firms to undertake the socially optimal (efficient) investment decisions in new competing infrastructures. Such facilities-based competition achieves the full benefits of competition, and hence, the consumers enjoy the full welfare gains from dynamic efficiency (maximum market growth in terms of both volume and value so that markets achieve minimized costs, innovative technologies and advanced services).

[3] See Cambini and Jiang (2009) for an excellent review of the theoretical and empirical literature on the relationship between broadband investment and regulation.

obligation of non-discrimination (EU, 2002), currently, price discrimination is allowed to a certain (at least wholesale) extent related to NGA networks in Europe in order to foster innovation and welfare growth by promoting investments (EC, 2010b). Bourreau, Cambini and Hoerning (2013) assume that differentiated wholesale access schemes vary according to the degree of infrastructure competition and point out that the regulator faces a dilemma between setting a lower access charge to maximize per-area welfare by maintaining lower retail prices, and setting a high access charge to maximize investment incentives. They show that differentiated remedies (where access is regulated in non-competitive areas, while access is privately negotiated in competitive areas) can be either too high or too low from a social perspective.

From the above analysis, it can be deduced that the derivation of an optimal regulatory policy that promotes both NGA investment and competition is a very difficult and complex task since it requires the estimation of the impact of four interrelated decisions on the twofold regulatory goal. This task becomes even more complex if we take into account the previously overlooked fact that the deployment of an NGA network is a two-dimensional investment decision.

### *1.2. The two dimensions of an NGA investment decision*

A potential investor in an NGA network has to decide: (i) the quality of the NGA network which is closely related to the provided NGA technology, and hence, to the provided internet connection speeds; and (ii) the geographic coverage of the NGA deployment.

The first decision is related to the part of the copper wire being replaced by fibre optics. There are certain NGA architectures, the most common of which are: (i) Fibre-to-the-Curb (FTTC); (ii) Fibre-to-the-Building (FTTB); and (iii) Fiber-to-the-Home (FTTH). It is obvious that the higher the part of the copper wire being replaced by fibre optics, the higher the internet connection speeds that can be provided to end-users. However, the quality of the NGA network is not only affected by the particular point of the local loop at which the fibre is terminated, but also by the particular access technology used to implement each architecture. In particular, the FFTH architecture can be implement by using either the point-to-point (P2P) connectivity technology, in which each device at the subscriber premises is connected through a dedicated optical fibre to a switch port located at the central office of the investor, or the point-to-multi-point (P2M)/ passive optical network (PON) connectivity technology which divides an optical signal into several shared connections. As a result, an investor in NGA network has to decide the combination of the NGA architecture and the connectivity technology that leads to a deployment of an NGA network of a particular quality (or NGA technology). This decision is closely related to the internet connection speeds that will be provided by the investor to its consumers. The second decision concerns the geographical extent of the NGA deployment. Therefore, the investor also chooses the geographic areas in which a fibre-based access network will be deployed. This decision determines the geographic NGA coverage.

Although the research papers that study the impact of the four interrelated regulatory decisions on investment incentives and competition outcomes separately treat the two dimensions of an NGA investment decision, it should be noted that the investor’s decisions concerning the NGA technology and the geographic NGA coverage are closely related. In particular, existing studies assume that a prospective investor in NGA networks chooses either the quality or the geographic coverage of the NGA network. This implies that the investor decides: (i) the quality of the NGA network that will be provided in an exogenously given number of geographic areas; or (ii) the number of geographic areas in which an exogenously given NGA technology network will be deployed. In each case, the investor focuses on one of the two dimensions of the NGA investment decision by taking the other dimension as given. A reasonable extension would be to consider a static modeling approach in which an investor endogenously chooses its optimal NGA technology network that will be deployed only in the geographic areas that the investment is proven to be profitable.

This paper goes one step beyond and models the fact that the investor chooses the NGA technology that will be provided in each geographic area.[4] Therefore, not only the quality of the NGA network and the coverage of the NGA deployment are both endogenously chosen by the investor, but also different NGA technologies may co-exist according to the prevailing demand and cost conditions in each geographic area. This modeling setup is the first step towards studying an operator’s incentives to deploy a geographically differentiated NGA network. As a result, this paper derives the provided NGA technology in each geographic area, as well as, the optimal number of areas that will be upgraded to any NGA technology. In addition, it compares the privately optimal two-dimensional investment decision with the socially optimal geographically differentiated NGA deployment. In other words, the aim of this paper is to assess whether the regulatory decision to allow an investor to deploy a quality-differentiated NGA network can promote both static and dynamic efficiency (i.e. induces the socially optimal investment outcome).

It should be noted that the derived results are comparable to the objectives of the Europe 2020 Strategy (EC, 2010b) which envisions that, by 2020, (i) all Europeans will have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps. It is obvious that these goals concern both the NGA technology and the NGA coverage, and hence, the research focus should shift towards modeling approaches that take into account the fact that the NGA deployment is a two-dimensional investment decision which results in a geographically differentiated NGA deployment.

The remainder of the paper is structured as follows. Section 2 gives an outline of the basic assumptions and definitions of the model. Section 3 compares the privately and the socially optimal investment levels in terms of both quality and geographic coverage in order to assess whether the investor undertakes the socially optimal investment decision. The last section summarizes the main results of this article and proposes the directions for future work.

## 2. The model

This section presents an innovative modeling setup which aims at reflecting the fact that the NGA deployment is a two-dimensional investment decision which concerns both the NGA technology and the geographic NGA coverage. Since the

[4] In fact, the investor has also to decide the time at which it will build an NGA network of a particular quality in each geographic area. However, the optimal timing of an NGA investment is studied using dynamic modeling approaches, and hence, is out of the scope of this paper, although we acknowledge that it provides an excellent field for future research.

goal of the paper is to assess whether the regulatory decision to allow an investor to deploy a different quality NGA network in each geographic area can promote both investment and social welfare, all the other regulatory decisions are exogenously chosen in order to simplify the model as much as possible. In particular, it is assumed that the investor is not obliged to provide access to its improved access infrastructures to its competitors, which implies that the monopolist firm invests in NGA networks under regulatory forbearance. Although such monopolistic regime does not resolve the trade-off between static and dynamic efficiency, the study of the derived investment outcomes is very useful for comparison purposes since they obviously represent the upper limit of the investment level. It is further assumed that the deployment of an NGA network eliminates the services provided over the pure copper access network (e.g. ADSL), and hence, the impact of the access price applied to the copper access network is of no significance. The last assumption made concerns the imposition of geographically differentiated remedies. In particular, the monopolist investor is allowed to geographically price discriminate in the retail market, which of course, increases its investment incentives compared to the uniform pricing regime (Alexandrov and Deb, 2012; Tselekounis, Maniadakis and Varoutas, 2013; Valletti, 2006).

The model used in this paper is based on a hypothetical country consisting of a continuum of geographic areas which can be indexed in a decreasing order according to their population density. In particular, geographic areas are indexed by $i$ with $i \in [1, n]$, where low values of $i$ imply geographic areas with high population density, whereas geographic areas that are indexed by $i$ close to $n$ represent rural areas (i.e. with low population density). A monopolist provides a basic "universal-level" broadband service (e.g. ADSL) to all geographic areas at a uniform price. Now assume that the monopolist invests in access network upgrade by deciding which geographic areas will be passed by any technology NGA network and which NGA quality will be provided in each geographic area. Therefore, the monopolist initially determines the geographic extent of the NGA deployment denoted by $x_{\max} \in [1, n]$ and then decides which NGA technology denoted by $y_i \in [y_i^{\min}, y_i^{\max}]$ will be provided in each geographic area $x_i$, $i \in [1, n]$. Obviously both investment decisions are continuous in $[1, n]$ and $[y_i^{\min}, y_i^{\max}]$, respectively. It is expected that the most densely populated geographic area ($x_1$) will be covered by the highest quality NGA network ($y_i^{\max}$), whereas the least densely populated, but NGA-passed, area ($x_{\max}$) will be covered by the lowest quality NGA network ($y_i^{\min}$).

Contrary to the existing studies which assume that a higher level of NGA investment in terms of either technology or coverage leads to a more outward parallel shift in the demand curve (and thus equally benefits all consumers), this paper models the fact that a higher NGA technology network positively affects the consumers' willingness to pay for ultra-fast NGA-based services, but its impact declines as it is provided to more rural areas. The reason is that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) densely populated areas (EC, 2010b; Götz, 2013; Preston, Cawley and Metykova, 2007). In addition, the investment cost is assumed to be increasing and convex reflecting the fact that the NGA investment becomes marginally more expensive as a better quality NGA network is deployed in order to provide end-users with higher internet connection speeds. However, contrary to existing studies which assume an exogenously given slope of the marginal investment cost function, this paper models the fact that the investment cost of providing a particular NGA technology becomes marginally more expensive as it is extended to less densely populated areas. Once again, population density has been proven to be an effective proxy for reflecting the fact that the investment cost per potential user decreases in the population density (Götz, 2013). It is thus obvious that geographic areas not only differ with respect to the cost of rolling out an NGA network of a particular technology, but also with respect to the impact of such NGA deployment on consumers' willingness to pay. Therefore, the demand and the investment cost functions in each geographic area  are given, respectively, by:

$$p_i = A + \frac{y_i}{x_i^2} - \beta q_i \tag{1}$$

and

$$C(i) = \frac{x_i y_i^2}{2} \tag{2}$$

where $p_i$ and $q_i$ denote the retail market price and the quantity supplied, respectively, in each geographic area, $\beta > 0$ represents the slope of the inverse demand function and $A$ represents the maximum valuation that the consumers place to the services provided over the pure copper access network when the NGA investment has not taken place. In addition, $x_i$ reflects the geographic NGA deployment and $y_i$ reflects the NGA technology. A larger $x_i$ implies an NGA deployment to less densely populated areas, whereas a larger $y_i$ implies a fibre deployment closer to the consumers' premises combined with a better connectivity technology. It is obvious that a higher NGA technology positively affects the consumers' willingness to pay, but its impact declines as it is provided to more rural areas. In addition, the investment cost of providing a higher NGA technology becomes marginally more expensive as it is extended to less densely populated areas.

## 3. Investment and welfare outcomes

This section studies the incentives of an unregulated monopolist to undertake the socially optimal investment decision in terms of both NGA technology provided in each geographic area and geographic coverage of the NGA deployment. As usual, the game is solved backwards. This implies that in the third stage, the investment cost is sunk and the monopolist sets the geographic differentiated retail prices of the different ultra-fast broadband services provided in each area given the level of NGA deployment chosen in the first stage and the quality of the NGA network chosen in the second stage.

### *3.1. Privately optimal level of NGA technology*

The profit function of the investor (net of investment cost) derived from the investment $y_i$ in each geographic region $x_i$ is given by:

$$\Pi_i = p_i q_i \tag{3}$$

Substituting the solution of Eq. (1) with respect to $q_i$ in Eq. (3) and taking the first order condition with respect to $p_i$ gives the retail market price that maximizes the monopolist's profits in each geographic area.

$$p_i^* = \frac{Ax_i^2 + y_i}{2x_i^2} \tag{4}$$

As a result, the optimum quantity supplied in each geographic area is given by:

$$q_i^* = \frac{Ax_i^2 + y_i}{\beta\left(2x_i^2\right)} \tag{5}$$

Obviously, both the retail price and the quantity supplied in each geographic area are positively affected by a higher NGA technology and a higher population density. Substituting Eqs. (4) and (5) into Eq. (3) and taking into account the investment cost in each geographic area given by Eq. (2) yields the profits of the investor in each geographic area as a function of the NGA technology ($y_i$) and the index of the corresponding geographic area ($x_i$).

$$\Pi_i = \frac{1}{\beta}\left(\frac{Ax_i^2 + y_i}{2x_i^2}\right)^2 - \frac{x_i y_i^2}{2} \tag{6}$$

Taking the first order condition of Eq. (6) with respect to $y_i$ gives the quality of the NGA network that maximizes the monopolist's regional profits.

$$y_i^M = \frac{Ax_i^2}{2\beta x_i^5 - 1} \tag{7}$$

Equation (7) shows the level of NGA technology $y_i$ that the monopolist investor is willing to install in each geographic area $x_i$. Obviously, the privately optimal level of the NGA technology is different among the various geographic areas. In particular, by studying the first and second derivatives of Eq. (7) with respect to $x_i$, it is concluded that the privately optimal level of NGA technology in each geographic area is a decreasing and convex function of $x_i$. This implies that the unregulated monopolist chooses a geographically differentiated NGA network in terms of the provided quality. In other words, the less (more) densely populated a geographic area is, the less (more) the extent of NGA upgrade that maximizes the investor's regional profits.

### *3.2. Socially optimal level of NGA technology*

Social welfare is the unweighted sum of profits and consumer surplus. Given that the consumer surplus in each geographic area is given by $CS_i = \beta\left(q_i\right)^2 / 2$, it is deduced that the socially optimal level of NGA technology should maximize the following social welfare function:

$$SW_i = \frac{1}{\beta}\left(\frac{Ax_i^2 + y_i}{2x_i^2}\right)^2 - \frac{x_i y_i^2}{2} + \left(\frac{\beta}{2}\right)\left(\frac{Ax_i^2 + y_i}{\beta(2x_i^2)}\right)^2 \tag{8}$$

Therefore, the socially optimal level of NGA technology is given by taking the first order condition of Eq. (8) with respect to $y_i$:

$$y_i^{SW} = \frac{3Ax_i^2}{4\beta x_i^5 - 3} \tag{9}$$

**Assumption 1.** Let $4\beta x_i^5 - 3 > 0$.

Assumption 1 ensures that the privately and the socially optimal levels of NGA technology are both positive in each geographic area. In particular, $\beta x_i^5 > 0.75$ is a sufficient condition to ensure that $y_i^M, y_i^{SW} > 0$.

In addition, by studying the first and second derivatives of Eq. (9) with respect to $x_i$, it is deduced that the socially optimal level of NGA technology in each geographic area is also a decreasing and convex function of $x_i$. This implies that the society is better off by a geographically differentiated NGA network in terms of the provided quality.

### *3.3. Comparison of privately and socially optimal levels of NGA technology*

The comparison of Eqs. (7) and (9) shows that the level of NGA investment in quality in each geographic area imposed by the investor's private investment incentives is less than the corresponding socially optimal level of NGA investment in quality (i.e. $y_i^M < y_i^{SW}$).

**Proof.** $y_i^{SW} > y_i^M \Leftrightarrow \frac{3Ax_i^2}{4\beta x_i^5 - 3} > \frac{Ax_i^2}{2\beta x_i^5 - 1} \Leftrightarrow 6\beta x_i^5 - 3 > 4\beta x_i^5 - 3 \Leftrightarrow 6 > 4$ ■

Therefore, the following proposition can be stated:

**Proposition 1.** *The unregulated investor always underinvests compared to the socially optimal investment level of NGA quality (or technology).*

The above result is graphically presented by Figure 1. The solid line reflects the privately optimal NGA quality provided in each geographic area, whereas the dashed line reflects the corresponding socially optimal level.

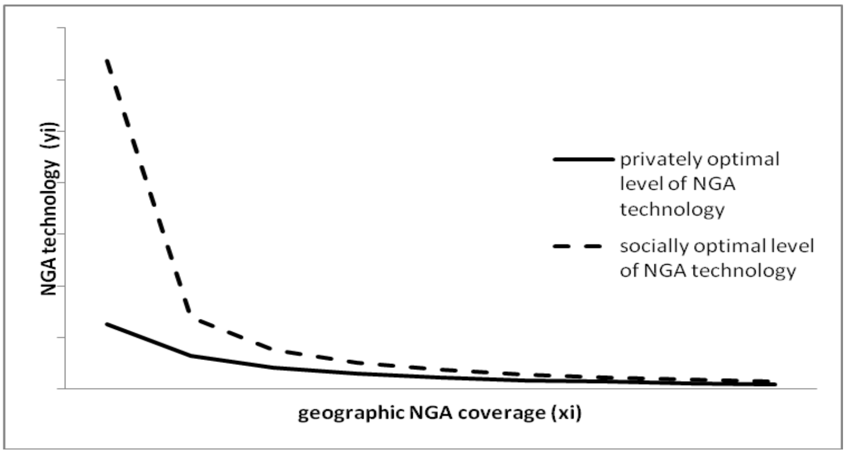


**Figure 1.** The relationship between $x_i$ and $y_i$ from a private and a social perspective ($A = 10$ and $\beta = 0.8$)

### 3.4. Privately and socially optimal levels of geographic NGA coverage

The goal of this section is to derive the privately and the socially optimal levels of geographic NGA coverage. In other words, this section aims at assessing the least densely populated geographic area that will be upgraded to any NGA technology when the investor is the unregulated monopolist and when the NGA investment is undertaken by the society. Substitution Eq. (7) into Eq. (6) gives the regional profits of the investor:

$$\Pi_i = \frac{A^2 x_i^5}{2(2\beta x_i^5 - 1)} \tag{10}$$

It is obvious that the investor's profits in each geographic area are positive. This implies that the unregulated investor is willing to deploy a nationwide quality-differentiated NGA deployment, although the installation of fibre optics in the local loop will be far away from the consumers' premises at the less densely populated areas. This fact gives rise to the following proposition:

**Proposition 2.** *When the unregulated investor is allowed to deploy a geographically differentiated NGA network, it is willing to invest in all geographic areas within a given country, although the fibre deployment in the less densely populated areas is rather insignificant.*

This result is a very interesting finding since is in contrast with existing studies which conclude that there is an optimal (one-dimensional) investment level that maximizes the investor's profits. Of course, the result of proposition 2 is due to the ability of the investor to maximize its regional profits by providing a different NGA quality network in each geographic area.

However, it is practical to limit our study to the lowest quality NGA network that is technically available. This is the Fibre-to-the-Curb (FTTC) architecture that provides internet connection speeds from 30Mbps to 100Mbps. Obviously, this is the reason that the Digital Agenda for Europe envisions that, by 2020, all Europeans will have access to internet speeds of at least 30Mbps.

Therefore, it is assumed that the highest quality NGA network is achieved by the P2P architecture (which can provide internet connection speeds of up to 1000Mbps) and is denoted by $y^{P2P}$. It is reasonable to consider $y_i^{\max}$ corresponds to the socially optimal level of NGA technology provided in the most densely populated area. This level is derived by setting $x_i = x_1 = 1$ in Eq. (9). Therefore:

$$y_i^{\max} = y_1^{SW} = \frac{3A}{4\beta - 3} \tag{11}$$

It is obvious that $y_i^{\max}$ takes its maximum value when the denominator of Eq. (11) is minimized. The solution of $4\beta - 3 > 0$ is $\beta > 0.75$, which implies that $\beta \geq 0.8$ is a sufficient condition to ensure that $y_1^{SW} > 0$. Moreover, given that $\beta$ negatively affects the optimal level of investment in quality, the highest internet connection speed is achieved for $\beta = 0.8$, and hence, $y^{P2P} = y_1^{SW}(\beta = 0.8)$, which implies that $y^{P2P} = 15A \equiv 1000\text{Mbps}$. Note that in the most densely populated area the privately optimal level of NGA technology is given by setting $x_i = x_1 = 1$ in Eq. (7) and is maximized for $\beta = 0.8$. Hence:

$$y_1^M = \frac{A}{2\beta - 1} = 1.667A \tag{12}$$

As a result, the minimum threshold of the internet connection speed that is acceptable in the present study (i.e. 30Mbps) will be provided to the least densely populated area in which an NGA network will be deployed. Let denote this geographic are by $\overline{n} \in [1, n]$. Therefore:

$$y_i^{\min} = y_{\overline{n}} = \frac{30}{1000} y^{P2P} \Rightarrow y_i^{\min} = \frac{45}{100} A \Rightarrow y_i^{\min} = 0.45A \tag{13}$$

Equating Eqs. (13) and (7) and solving with respect to $x_i$ gives the geographic area in which the monopolist investor will deploy the minimum quality NGA network. In addition, equating Eqs. (13) and (9) and solving with respect to $x_i$ yields the socially optimal geographic area covered by the minimum quality NGA network. The former geographic area reflects the privately optimal geographic NGA coverage denoted by $x_{\max}^M = \overline{n}$, whereas the latter reflects the socially optimal geographic NGA coverage denoted by $x_{\max}^{SW}$. Since both levels of geographic coverage are affected by the slope of the inverse demand function, table 1 provides the levels of $x_{\max}^M$ and $x_{\max}^{SW}$ for the values of $\beta$ that ensure a positive geographic NGA development (i.e. $x_{\max}^M > 1$, or equivalently, $\beta \in [0.8, 1.6]$).

**Table 1** (for $A = 10$ and $y_i^{\min} = 0.45\text{A}$)

| $\beta$ | $x_{\max}^M$ | $x_{\max}^{SW}$ |
|---|---|---|
| 0.8 | 1.21863 | 1.37180 |
| 0.9 | 1.17805 | 1.32505 |
| 1 | 1.14312 | 1.28483 |
| 1.1 | 1.11261 | 1.24970 |
| 1.2 | 1.08562 | 1.21863 |
| 1.3 | 1.06149 | 1.19087 |
| 1.4 | 1.03974 | 1.16585 |
| 1.5 | 1.01998 | 1.14312 |
| 1.6 | 1.00191 | 1.12235 |
| 1.7 | 0.98530 | 1.10326 |

Table 1 reveals that the unregulated monopolist underinvests compared to the socially optimal geographic NGA coverage (i.e. $x_{\max}^M < x_{\max}^{SW}$). This is an expected result since the socially optimal level of NGA technology in each geographic area is always higher than the corresponding privately optimal level, and hence, the same level of NGA technology (which, in this case, corresponds to 30Mbps) is privately provided to a more densely populated area than the corresponding socially optimal geographic area.

Table 1 also provides useful implications about the feasibility of the first goal of the Digital Agenda for Europe concerning the provision of access to much higher internet speeds of above 30 Mbps to all Europeans. Assuming that the EC sets its objectives from a social rather than an industrial perspective as well as that the European households are uniformly distributed to all geographic areas, the total number of the households of a given country will correspond to a particular value of $x_{\max}^{SW}$ denoted by $\hat{x}_{\max}^{SW}$. In turn, $\hat{x}_{\max}^{SW}$ corresponds to a particular value of $\beta$ denoted by $\hat{\beta}$. Therefore, if the demand for ultra-fast broadband services is more inelastic than $\hat{\beta}$ (i.e. $\beta > \hat{\beta}$), then the achievement of the first goal of the Digital Agenda for Europe is not feasible. On the contrary, when $\beta < \hat{\beta}$, the fulfillment of this goal is feasible when the privately optimal NGA coverage is at least equal to the socially optimal NGA coverage derived by $\hat{\beta}$. In this case, the monopolist provides all households with at least 30Mbps. The particular value of $\beta$ that leads to the provision of 30Mbps in the least densely populated area of a given country is given by:

$$y_{\bar{n}}^{M}(\beta) = y_{\bar{n}}^{SW}(\hat{\beta}) \Rightarrow \frac{Ax_{\bar{n}}^{2}}{2\beta x_{\bar{n}}^{5} - 1} = \frac{3Ax_{\bar{n}}^{2}}{4\hat{\beta} x_{\bar{n}}^{5} - 3} \Rightarrow \beta = \frac{2}{3}\hat{\beta} \tag{14}$$

Equation (14) implies that the first goal of the Digital Agenda for Europe is feasible when $\beta \leq 66,7\%\hat{\beta}$. For instance, assume that the total number of households correspond to the geographic area $x_i = 1.14312$, which in turn corresponds to $\hat{\beta} = 1.5$ . According to Eq. (14), the monopolist will provide this least populated area with at least 30Mbps if $\beta \leq 1$. Indeed, table 1 shows that the privately optimal geographic NGA coverage is $x_{\max}^{M} = 1.14312$ when $\beta = 1$ . For $\beta < 1$, internet connection speeds of above 30Mbps are provided to all households.

In other words, the slope of the inverse demand function for NGA-based services should be significantly flatter than the respective slope that leads to the provision of 30 Mbps to all households by the socially optimal investment in geographic coverage. The reason is that as the demand for NGA-based services becomes more elastic, the effectiveness of price discrimination to decrease consumer surplus in favor of the monopolist is limited, and hence, the monopolist has incentives to extend its NGA coverage to more geographic areas.

This paper can also assess the feasibility of the second objective of the Digital Agenda for Europe, which refers to the goal of achieving the provision of internet connection speeds of 100 Mbps to 50% or more of European households. This goal is equivalent to providing half of the households in each European country with internet connection speeds of 100 Mbps. Given that $y^{P2P} = 15A$ represents the internet connection speed of 1000Mbps, the respective speed of 100Mbps is given by:

$$y_i^{'} = \frac{1}{10} y^{P2P} \Rightarrow y_i^{'} = 1.5A \tag{15}$$

According to Eq. (7), the unregulated monopolist is willing to provide this internet connection speed to a particular geographic area. This area is derived by equating Eqs. (7) and (14) and solving with respect to $x_i$. Since the derived level of $x_i$ is a function of $\beta$, table 2 provides the geographic area in which the installed NGA network will provide internet speeds of 100Mbps ($x_{\max}^{M'}$) as well as the respective socially optimal geographic NGA coverage.

**Table 2** (for $A = 10$)

| $\beta$ | $x_{\max}^{M'}$ | $x_{\max}^{SW}$ |
|---|---|---|
| 0.8 | 1.00978 | 1.37180 |
| 0.9 | 0.98188 | 1.32505 |
| 1 | 0,95772 | 1,28483 |
| 1.1 | 0,93649 | 1,24970 |
| 1.2 | 0,91760 | 1,21863 |
| 1.3 | 0.90064 | 1.19087 |
| 1.4 | 0.88528 | 1.16585 |
| 1.5 | 0.87125 | 1.14312 |
| 1.6 | 0.85838 | 1.12235 |
| 1.7 | 0.84649 | 1.10326 |

Table 2 reveals that the monopolist invests in the provision of internet connection speeds of above 100 Mbps only when the demand for the NGA-based services is extremely elastic (i.e. $\beta \in (0.75, 0.833]$ since $x_i \in [1, n]$). However, in order to assess whether the derived values of $x_{\max}^{M'}$ represent the 50% of the national households, we should first define the total number of the households of a given country. Once again, we use as a point of reference the critical value $\hat{\beta}$ which corresponds to the provision of 30 Mbps to all households under the socially optimal investment in coverage as presented by the second column of the above table. It is obvious that regardless of the particular value of $\hat{\beta} \geq 0.8$, the provision of internet connection speeds of 100 Mbps is much less than 50% of the total households. The reason is that the ratio of ($x_{\max}^{M'} - 1$) to any value of ($x_{\max}^{SW} - 1$) is lower than 50%.[5] Therefore, the second objective of the Digital Agenda for Europe is not a feasible goal.

## 4. Conclusions

The goal of this paper was to study the incentives of an unregulated monopolist to undertake the socially optimal investment in NGA networks when it takes into account the fact that the NGA deployment is a two-dimensional investment decision. In particular, the investor has to decide the quality of the NGA network and the geographic coverage of the NGA network. For this reason, a suitable modeling setup was used in order to reflect the fact that as an investment in quality upgrade extended to less densely populated (i.e. more rural) areas, not only it has a declining positive impact on the consumers' willingness to pay, but also becomes marginally more expensive. This paper highlighted the expected

[5] This result holds under the assumption that the household density in each geographic area follows the same distribution as the population density.

result that the investor is better off by deploying a geographically differentiated NGA network (i.e. by installing a different quality NGA network in each geographic area).

The main result of this paper was that although a geographically differentiated NGA investment provides the unregulated monopolist with incentives to install a nationwide NGA deployment, the monopolist underinvests compared to the socially optimal levels of both quality and geographic coverage. However, the fibre deployment in the less densely populated areas was found to be rather insignificant, and hence, certain assumptions were made in order to make the derived results comparable to the Europe 2020 Strategy which envisions that, by 2020: (i) all Europeans will have access to much higher internet speeds of above 30 Mbps; and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps. It was shown that the former objective is feasible when the demand for NGA-based services is significantly elastic, whereas the latter is not a feasible goal.

Our framework is suitable to be extended in many different directions. Firstly, the focus of regulators is continuously shifting from the regulation of the retail market to the regulation of the wholesale market, and hence, the introduction of competition between an investor and an access seeker will certainly highlight the role of access regulation in encouraging NGA investments and promoting competition. Secondly, it is reasonable to expect that a geographically differentiated NGA deployment calls for geographically differentiated access remedies. Therefore, the modeling approach of Bourreau, Cambini and Hoernig (2013) which studies the impact of differentiated wholesale access schemes on coverage and welfare should be combined with the modeling setup of this paper in order to conclude about the optimal pricing scheme that leads to the socially optimal geographically differentiated NGA deployment. A last interesting extension concerns the introduction of some dynamics in our setting since the most significant factors that affect the NGA deployment change over time. In this case, particular focus should be given on the impact of regulatory uncertainty on investment incentives. The reason is that variations in the demand and cost conditions may require regulatory remedies that change over time which, in turn, increase the risk of an *ex ante* NGA deployment.

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# A CDS approach to induce facilities-based competition over NGA networks

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ABSTRACT

The current regulatory framework in the European NGA market provides the basic principles for the gradual migration from service-based competition over the legacy copper access networks to facilities-based competition over fibre-based Next Generation Access (NGA) networks. This paper initially reviews the related literature and shows that: (i) an unbundling policy that boosts entry by alternative operators promotes service-based competition but provides operators with disincentives to invest in network upgrade; (ii) there is no consensus about the optimal regulatory policy that promotes competition and encourages investments in NGA networks; and (iii) the reviewed research articles are not consistent with the current regulatory framework in the European NGA market in terms of both the evolution of the regulatory goals over time and the recommended regulatory settings. This paper aims to propose a novel approach in order to effectively meet the current regulatory goals using the recommended settings. It is shown that the proposed approach, which is based on the basic principles governing a Credit Default Swap (CDS), provides an effective migration path towards facilities-based competition over NGA networks.

Keywords: access regulation; Credit Default Swap (CDS); facilities-based competition; investment incentives; Next Generation Access Networks (NGA)

## 1. Introduction

The Telecommunications Act of 1996 (FCC, 1996) passed by US Congress and administered by the Federal Communications Commission (FCC), as well as, the European Commission's (EC) Regulation on Local Loop Unbundling (EC, 2000) mandated unbundled access to the metallic local loops of incumbent operators at cost-based prices. The short-run goal of this unbundling policy was to reduce the incumbent's market power in order to enable alternative operators (new entrants) to enter the market and compete effectively with the incumbent in the retail (downstream) market. Therefore, operators would compete on their services (service-based competition), and hence, consumers would enjoy the welfare gains from static efficiency (i.e. existing assets are used efficiently and prices are driven towards marginal cost). Armstrong (2002), Valletti (2003) and Vogelsang (2003) summarize the optimal access pricing policy in different static contexts, in which it is appropriate to apply cost-based access pricing, Ramsey pricing and the Efficient Component Pricing Rule (ECPR).

However, the long-run goal of this unbundling policy was to promote investments in new network infrastructures from the incumbents, and especially entrants. In this case, operators would compete on their facilities (facilities-based competition) rather than on their services, and hence, consumers would enjoy the welfare gains from dynamic efficiency (i.e. the encouragement of investments in competing infrastructures and the deployment of new technologies). In particular, facilities-based competition is regarded as the only means to achieve sustainable competition (Cave, 2006; Oldale and Padilla, 2004) since it creates a level playing field between the incumbent and the entrants (De Bijl and Peitz, 2002). In addition, a growing number of empirical studies conclude that facilities-based competition has been the main driver for broadband diffusion (Bouckaert, van Dijk and Verboven, 2010; Denni and Gruber, 2007; Distaso, Lupi and Manenti, 2006; Höffler, 2007) although they do not find a negative relationship between service-based competition and broadband diffusion. Given that broadband penetration positively affects economic growth (Greenstein and McDevitt, 2009; Koutroumpis, 2009), it can be deduced that facilities-based competition creates a superior potential for economic growth than does service-based competition.

Many research articles try to model such unbundling practices and assess their effectiveness and efficiency implications both theoretically and empirically.[1] Using different theoretical models of downstream competition, Foros (2004) and Kotakorpi (2006) show that cost-oriented access prices discourage incumbents to invest in network upgrade unless they are much more efficient than their rivals in the downstream market. Sarmento and Brandao (2007) also find a negative relationship between cost-based access prices and the incumbents' incentives to invest even if the incumbents are partially compensated for the investment cost. Not only the incumbents' investment incentives are negatively affected by cost-oriented access prices, but also the new entrants' investment decisions are negatively influenced. Valletti (2003) argues that potential entrants, who can free-ride on the incumbent's network, will wait for the incumbent to invest in access infrastructure and then seek access. In addition, Bourreau and Doğan (2005, 2006) show that unbundling of the local loop may delay the entrants' investments, even in an unregulated environment. Grajek and Röller (2009) empirically confirm the negative impact of an unbundling policy that boosts entry by alternative

[1] See Cambini and Jiang (2009) for an excellent review of the theoretical and empirical literature on the relationship between broadband investment and regulation.

operators on incentives to invest in facilities-based competition. In particular, they use a comprehensive panel data set (180 fixed-line operators in 25 European countries observed from December 1997 to December 2006) in order to show that unbundling results in a significant negative effect on the incumbents' incentives to invest in network upgrade, whereas easier access pushes entrants towards service-based competition.

It is thus obvious that cost-based access prices disincentivize both the incumbents and the entrants to invest in network upgrade. On the other hand, cost-based access prices have been proven very effective in promoting static efficiency. Indeed, by analyzing the results of Tselekounis, Varoutas and Martakos (2012), it can be deduced that when the access is priced at cost, the productively efficient make-or-buy decision undertaken by the entrant is always socially optimal. The main conclusion of the above studies is that an unbundling policy that boosts entry by alternative operators promotes service-based competition but leads to losses in dynamic efficiency (Bouckaert, van Dijk and Verboven, 2010). This implies that cost-oriented access prices is an effective regulatory tool for fostering service-based competition over the legacy copper access networks, which were largely deployed by public funds, but they cannot promote investments in new fibre-based access infrastructures (the so-called Next Generations Access Networks, or NGAs) by either incumbents or entrants.

However, the need for the deployment of NGA networks is almost imperative. Firstly, the number of internet users, as well as, the capacity they demand have increased dramatically during the last decade. As a result, the increasing transmitted volume of data has made the traditional access copper networks incapable of providing end-users with the demanded bandwidth. On the contrary, NGA networks are the only future-proof solution capable to handle future demand (Shumate, 2008) since the transmission capabilities of fibre are theoretically unlimited, whereas it also provides high data rates, low loss and low distortion. Secondly, investments in broadband infrastructure have an indisputable positive effect on broadband diffusion, economic growth, job creation and consumers' welfare (Czernich, Falck, Kretschmer and Woessmann, 2011; ITU, 2012; Katz, Vaterlaus, Zenhäusern and Suter, 2010; Reynolds, 2009).

These two reasons partially interpret why national governments rank among their top priorities the encouragement of investments in NGA networks rather than the promotion of facilities-based competition. The US government's National Broadband Plan (FCC, 2010) and the European Commission's Digital Agenda for Europe (EC, 2010a) are examples of these perceived political priorities for the diffusion of broadband infrastructure access and services.

Considering the above-mentioned technical and economic issues that make the need for investments in NGA networks imperative, as well as, the inappropriateness of cost-based access prices for promoting such investments, the European Commission (EC) issued a Recommendation on regulated access to NGA (EC, 2010b) providing the National Regulatory Authorities (NRAs) with guidelines for tackling the trade-off between fostering competition and promoting investments with regard to NGA networks. Section 2 discusses the EC Recommendation, as well as, its impact on competition and firms' investment incentives. The main implication of this Recommendation is that the initial regulatory focus is to establish service-based competition over NGA networks, and then to promote facilities-based competition. This implies that regulators should initially tackle the trade-off between encouraging investments in NGA networks and promoting competition. Once service-based competition over NGA networks has been achieved, the disclosed regulatory policy should provide access seekers with incentives to invest in their own network infrastructures in order to be facilities-based competitors.

In addition, the ongoing academic research shifts its focus from assessing the effectiveness and efficiency implications of cost-oriented access schemes to proposing new regulatory approaches, and then assessing their efficiency and other performance implications. Thus, section 3 provides a review of the articles that depart from the main principles governing the regulation of the copper access networks (i.e. permanent regulation of the access at uniform cost-oriented prices) by proposing alternative regulatory settings that may promote both competition and investments in NGA networks.

In fact, there is a major difference between the reviewed research articles and the EC Recommendation. Existing research articles study the impact of alternative regulatory approaches on either an investment leader's or an investment follower's (access seeker) incentives to invest in NGA networks. However, in the former case, the existing studies do not take into account the access seeker's subsequent investment reaction, whereas in the latter case, they assume that the investment leader has already deployed an NGA network. On the contrary, the goal of the EC Recommendation is to propose an access scheme that encourage the initial investor to deploy an NGA network without distorting the competition level, and then to induce the access seekers to act as facilities-based competitors. Therefore, the current regulatory framework in the European NGA market requires a composite (rather than a separate) approach to induce a gradual migration from service-based competition over copper access networks to facilities-based competition over NGA networks. There are also minor differences between the existing literature and the EC Recommendation mainly in terms of the regulatory settings, such as the characteristics of the access pricing formula, the evolution of the access price over time and the provision of regulatory certainty. It is thus obvious that there is a gap between the existing literature and the current regulatory framework in the European NGA market.

This paper proposes an innovative regulatory approach which not only is consistent with the goal of the EC Recommendation, but also takes into account the recommended regulatory settings. In particular, the proposed approach is based on the basic principles governing a Credit Default Swap (CDS), which is a widely known financial tool for transferring credit risk. Section 4 provides a detailed description of this approach and discusses its impact on investment incentives and competition. The novelty of this approach is twofold. It is the first time that a financial instrument for transferring credit risk (in our case a CDS) is applied to the field of regulatory economics. It should be noted that this is not the first time that a pure financial tool is applied to the information and communications technology (ICT) industries. There is also a well known modification of the call option on a share of stock that aims to better value an ICT investment project. Such modification has led to the deployment of the so-called "real option" methodology. Furthermore, it is the first paper that aims to develop a model that reflects the current regulatory framework in the European NGA market. It is shown that, under plausible assumptions, the proposed approach provides an effective migration path towards facilities-based competition over NGA networks, and hence, resolves the standard trade-off between static and dynamic efficiency.

## 2. The current European NGA regulatory framework

Investment in NGA networks not only requires a high initial fixed cost but also is mainly sunk once the investment has been made. This implies that potential investors are reluctant to invest in NGA networks unless they are reimbursed for the risk they incur when investing in such networks. Although there are many factors influencing the riskiness of an NGA investment project[2], OPTA (2008) argues that the main factors that negatively affect an investor's incentives to invest in NGA networks are: (i) the uncertainty about future demand for new fibre-based services; and (ii) the regulatory uncertainty related to the regulator's limited ability to make *ex ante* credible commitments. The first type of uncertainty includes the uncertainty about: (i) the penetration of the customer base; (ii) the market shares of the investor and the access seekers; and (iii) the consumers' willingness-to-pay for the new fibre-based services. Concerning the second type of uncertainty, regulatory risk could be eliminated if the regulator fixes the principles of tariff regulation for the whole period of the economic lifecycle of an NGA investment. However, regulatory certainty bears the risk of erroneous intervention. According to WIK (2009), it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period. Therefore, in providing greater regulatory certainty the regulator has to make another trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare (OPTA, 2010).

The main conclusion is that regulators should provide the investors with significant incentives to invest in NGA networks without distorting competition. The EC issued a Recommendation on regulated access to NGA (EC, 2010b) providing the NRAs with guidelines for tackling the trade-off between fostering competition and promoting investments with regard to NGA. In particular, the aim of this Recommendation is "*to foster the development of the single market by enhancing legal certainty and promoting investment, competition and innovation in the market for broadband services in particular in the transition to next generation access networks*".

According to the Recommendation, where an investor operator with Significant Market Power (SMP) is found within Market 4 (market for wholesale network infrastructure access) and/or Market 5 (wholesale broadband access), an appropriate set of remedies should be applied. In particular, the EC recommends calculating the access in a cost-based form that incorporates a risk premium. This premium should reflect any additional and quantifiable investment risk incurred by the investor. Additional mechanisms serving to allocate the investment risk between investors and access seekers and to foster market penetration, such as *ex ante* and *ex post* contracts, could also be used.[3] In such cases, the risk premium is reduced accordingly.

It can thus be deduced that the initial goal of the current regulatory policy in Europe is to promote service-based competition over fibre networks. Given that the prospective investors in NGA networks (and probably the SMP operators) are

[2] For an extensive review of all the factors influencing the riskiness of an NGA investment project, see ERG (2009), pp. 17-18; WIK (2009), pp.1-7; and EC (2010b), page 18.

[3] Long-term access pricing and volume discounts are examples of *ex ante* and *ex post* contracts, respectively. See Inderst and Peitz (2012a) for a discussion about the impact of different contract types on competition and investment incentives.

for large part the former incumbent operators (OPTA, 2010; WIK, 2009), the regulatory goal is to provide the incumbents with significant incentives to invest in new fibre-based access networks and foster competition in the retail market. Although the EC argues that the incorporation of a risk premium into the access pricing formula can promote both investments and competition, Nitsche and Wiethaus (2011) support that a risk premium removes the structural disadvantages of investing only when the NGA investment turns to be successful. Otherwise, the incumbent has to bear all the cost alone since the risk premium does not have any impact on the incumbent's revenues.

In fact, when the incumbent makes an investment in an NGA network it gives up its option to wait to see how uncertainty about markets, costs, and regulations is resolved since network investments are largely irreversible (Pindyck, 2007). This "real option" is analogous to a financial "call option" in the sense that the incumbent has the right but not the obligation to invest in an asset at some future time of its choosing. Therefore, such lost option value reflects an opportunity cost that must be included as part of the cost of the investment (Dixit & Pindyck, 1994). Alleman, Madden and Kim (2008) provides an excellent summary of the literature that focuses on the application of real options methodology to the ICT industries and conclude that the magnitude of the option value is directly related to the level of uncertainty of future market conditions. As a result, any additional and quantifiable investment risk incurred by the investor reflects an option value which is translated to a higher risk premium over the cost-based access price.[4]

This view is also expressed by the European Telecommunications Network Operators' Association (ETNO), which comprises most of the European incumbents. It states that even if the probability of success is relatively high, the risk premium proposed by the EC Recommendation does not reflect the structural cost advantage of the second-movers (or, the access seekers) over the investors (ETNO, 2008). Firstly, the second mover can choose between a fixed and a variable cost structure when facing demand uncertainty, heterogeneity, geographical differences and demand evolving over time. This option is widely known as "make-or-buy". Secondly, the access seeker can exit the market at low cost (before making its own investment), whereas the investment of the first mover is typically sunk. Thirdly, the second mover has the option to enter the market once the critical mass has been created. This option is known as "wait-and-see". In addition, even if a risk premium results in higher wholesale revenues for the investor, raising prices for the new infrastructure may lead to a competitive disadvantage of NGA networks vis-à-vis competing platforms and the existing copper network that often will coexist with NGAs for some time. Therefore, ETNO concludes that the proposed risk premium will not solve the lack of incentives for widespread NGA roll-out in Europe unless it incorporates the incumbents' opportunity cost of giving up their "real option".

It is obvious that there is high ambiguity about the effectiveness of a risk premium on encouraging incumbents to invest in NGA networks. This ambiguity is enhanced by the fact that the appropriate array of remedies imposed by an NRA should reflect a proportionate application of the "ladder-of-investment" principle proposed by Cave and Vogelsang (2003). This theory is extensively presented

[4] Franklin and Diallo (2013) propose a model and methodology for valuing the option to delay network investment decisions and calculating cost-based access prices by taking into account the fact that an option value multiple must be calculated for each network element where a network element is an identifiable part of the network infrastructure.

and discussed in section 3.2 of this paper. Therefore, the ultimate goal of the current regulatory policy in Europe is to encourage the gradual migration from service-based to facilities-based competition over NGA networks.

In conclusion, the analysis of the regulatory economics of NGA investments showed that the optimal regulatory policy should be aligned with the current regulatory framework in the European NGA market described by the following four basic principles concerning:

**i) The evolution of the regulatory goals over time.** The regulatory policy should initially encourage the incumbent to invest in new fibre-based access networks and promote service-based competition over such networks. Once the new fibre-based access network has been deployed and service-based competition over such networks has been established, the regulatory policy should encourage the access seekers to invest in their own fibre infrastructures.

**ii) The characteristics of the access pricing formula.** The access to the incumbent's network should be provided at cost-oriented prices including a risk premium to reflect any additional and quantifiable investment risk incurred by the investor. Risk allocation mechanisms, such as long-term access pricing or volume discounts, which decrease the risk that an investor incurs when investing in NGAs, lead to a respective decrease in the risk premium. However, since the EC Recommendation does not include in such mechanisms the fixed-fee payments, it is deduced that two-part access tariffs do not reflect the current regulatory framework in the European NGA market. Therefore, NRAs should apply uniform (or usage or linear) access prices under a regime of permanent regulation as long as an SMP operator is found within markets 4 and/or 5.

**iii) The evolution of the access prices.** Access prices should be aligned with the EC statement that the appropriate array of remedies imposed by an NRA should reflect a proportionate application of the ladder-of-investment principle.

**iv) The provision of regulatory certainty.** According to the EC Recommendation, regulatory certainty is a key to promoting efficient investments by all operators. Applying a consistent regulatory approach over time is important to give investors confidence for the design of their business plans. In order to mitigate the uncertainty associated with periodical market reviews, NRAs should clarify to the greatest extent possible how foreseeable changes in market circumstances might affect remedies.

## 3. Literature review

In the introductory section, we showed that the permanent regulation of access at uniform cost-based prices, which is designed to stimulate competition in the market by facilitating entry of alternative operators, promotes static efficiency at the cost of dynamic efficiency.

Thus, this section reviews the research articles that shift their focus from the impact of the principles governing the regulation of the copper access networks on static and dynamic efficiency to the deployment of new regulatory approaches that may promote both static and dynamic efficiency (i.e. induce the socially optimal investments in NGA networks). Such alternative approaches depart from existing practices in terms of the access pricing formula and/or the regulatory regime employed.[5] In the former case the effectiveness of non-uniform or non-cost-based access prices on the levels of competition and investments is studied, whereas in the latter case the impact of non-permanent regulatory regimes on the timing of the investment decisions and on the subsequent competition level is discussed.

The reviewed research articles can be classified into three broad categories as proposed by Vogelsang (2010). The first strand deals with the effect of the regulated access price on the incumbents' incentives to invest in new infrastructures and on the subsequent competition level, independent of the effect on potential alternative competitors. The second strand deals with the incentive effects of unbundling obligations on the entrants' investments and on the subsequent competition level. Last, a third part of the access-related literature deals with incumbent and entrant investment decisions in models that capture a new industry, in which two firms have to decide, which one will invest first and in which access regulation has been established before.

### *3.1. Access regulation and an incumbent's incentives to invest*

This section studies the impact of alternative regulatory settings in terms of either the access pricing formula or the regulatory regime employed on the standard trade-off between promoting static and dynamic efficiency.

Klumpp and Su (2010) propose a uniform access price that spreads investment costs over total output quantities (which implies that the incumbent can recoup investment costs through the access prices) in order to show that such an access pricing scheme can promote both static and dynamic efficiency comparing with the monopolistic market (i.e. regulatory holidays). However, Nitsche and Wiethaus (2011) show that the result of Klumpp and Su (2010) is dependent on the particular regulatory regime and the assumption about regulatory uncertainty. Thus, they allow the access pricing scheme that spreads investment costs over total output quantities for taking into account different regulatory regimes, as well as, assume that the incumbent invests after the regulator has set the access price (i.e. regulatory certainty).[6] They show that a regime with fully distributed

[5] The following regulatory regimes are studied in the respective literature. **Permanent regulation** implies that the *ex ante* imposed remedies hold for the whole lifecycle of the NGA investment, whereas **regulatory forbearance** refers to the situation where there is no *ex ante* regulation on NGA networks. **Regulatory holidays** and **sunset clauses** are intermediate regulatory regimes between regulatory forbearance and permanent regulation. Under regulatory holidays, the investor is not imposed to any regulatory constraints for a predetermined period of time, whereas by imposing a sunset clause, the regulator commits that will withdraw access obligations after a predetermined date.

[6] In a static framework (or in a hypothetical world of economic certainty), the incumbent may invest under regulatory certainty if the investment decision is undertaken after the regulation of the access price. However, the regulation of the access is a dynamic process and regulatory remedies are also imposed after the investment decisions. Although theoretical static models are useful for giving an insight into regulatory policies, we should keep in mind that uncertainty can be reduced to risk, possibly even low risk, but not certainty. This fact is also considered in the EC Recommendation since NRAs are encouraged (in order to provide greater certainty) to clarify to the greatest extent possible (i.e. not to fully commit) how foreseeable changes in market circumstances might affect remedies.

costs (FDC) [7] or regulatory holidays induce highest investments, followed by risk-sharing and long run incremental costs (LRIC), which is a particular methodology of forward-looking cost-based regulation. In addition, in combining strong competitive intensity with reasonable investment incentives, simulations indicate that a risk sharing approach induces highest consumer surplus, followed by regimes with fully distributed costs, regulatory holidays and LRIC. Therefore, they conclude that risk-sharing can be an effective tool since it combines relatively high *ex-ante* investment incentives with strong *ex-post* competitive intensity. They also confirm that forward-looking cost-based regulation neither induces investments nor consumer surplus.

Contrary to the previous articles that study the impact of different regulatory regimes on the levels of investments and competition, Charalampopoulos, Katsianis and Varoutas (2011) and Gavosto, Ponte and Scaglioni (2007) use a real option approach in order to study the impact of four different regulatory regimes (permanent regulation, regulatory forbearance, regulatory holidays and sunset clauses) on the timing of the investment decision of an incumbent to expand to a new network infrastructure. The former article shows that regulatory holidays induce the incumbent to expand its current network as soon as the regulatory holiday season ends, which is long before the expiration date of the option to expand. The latter article concludes that investment is carried out immediately under forbearance and regulatory holiday regimes, while it is delayed by around two years in the other cases. Therefore, it can be deduced that both articles argue that regulatory holidays appear superior to the other regulatory regimes, although the two papers provide different results about the impact of regulatory holidays on the particular timing of the investment. In combining these results with those of Nitsche and Wiethaus (2011), it can be deduced that although regulatory holidays appear superior to the other regulatory regimes in terms of both NGA investment level and the timing of the investments, they fail to promote an efficient competition level. In this context, Tselekounis, Maniadakis and Varoutas (2013) show that the regulator should allow the monopolist to geographically price discriminate since such pricing regime results in better investment and welfare outcomes than uniform pricing as long as the investment cost is not extremely low.

Contrary to the aforementioned articles that study the efficiency implications of different regulatory regimes, Tselekounis and Varoutas (2013) study the impact of the uncertainty about future access prices on an incumbent's incentives to undertake the socially optimal investments in NGA networks. For this reason, they assume that the regulator sets the access price at the marginal cost of providing the access with some probability and gives an access markup, which equals the average cost of the investments, with the complementary probability. They found that when the slope of the marginal investment cost function is not particularly steep in relation to the impact of investments on demand, the incumbent underinvests compared to the socially optimal investment level. On the contrary, when the impact of investments on demand is low in relation to the slope of the marginal investment cost function, the incumbent may overinvest or

[7] Under the fully distributed costs regulation, the incumbent may recoup NGA investment costs through the access price, regardless of the NGA's market success since the entrant is forced to cover part of the investment costs.

underinvest depending on the probability of incorporating an access markup into the access price. Therefore, uniform access prices may lead to significant welfare losses due to the impact of regulatory uncertainty on investment incentives.

Brito, Pereira and Vareda (2010) study the impact of the regulatory commitment problem on the effectiveness of two-part access tariffs to solve the dynamic consistency problem of the regulation. They find that when the investment cost is low compared to the investment benefits, two-part tariffs solve the dynamic consistency problem either under regulatory certainty or uncertainty. In this case, the optimal regulatory policy is to set the fixed access price in order to induce investments by the incumbent and the usage access price at the marginal cost of providing the access in order to promote static efficiency. If, on the contrary, the investment cost takes intermediate values compared to the investment benefits, the commitment and the no-commitment games have different equilibria, with the incumbent investing in the commitment equilibrium, and not investing in no-commitment game. Last, if the investment cost is high compared to the investment benefits, investment is not socially desirable under both commitment and no-commitment games. Therefore, two-part access tariffs may not solve the dynamic consistency problem even when the regulator can commit *ex ante* to a particular access pricing policy.

### *3.2. Access regulation and an entrant's incentives to invest*

The second literature strand deals with the impact of access regulation on an entrant's incentives to invest in network upgrade. In particular, this literature studies whether service-based competition serves as a stepping stone to facilities-based competition or the presence of the option to "buy" the incumbent's facilities represents an opportunity cost when the entrant chooses to engage in infrastructure competition (i.e creates the so-called "replacement effect").

Cave and Vogelsang (2003) point out that entrants will typically invest in replicable assets first and then progress to less replicable ones. Thus, they rank the incumbent's network assets according to their degree of replicability from an entrant's perspective and propose an innovative access scheme in which the price for the less replicable network elements is low but increasing over time as assets are replicated. Therefore, as the entrant's customer bases grow, the access price increases in order to encourage the entrant to invest in the next less replicable asset. This process continues until the entrant invests in its own infrastructure which represents the higher rung in the investment ladder. Thus, the so-called "ladder-of-investment" theory argues that service-based competition serves as a stepping stone to facilities-based competition. Cave (2006) proposes and illustrates methods for assessing the replicability of different assets and sets out the steps which regulators can follow in implementing the approach. An alternative regulatory tool that resembles the ladder-of-investment approach is the already discussed "sunset clause" regulatory regime. By imposing a sunset clause, the regulator commits that will withdraw access obligations after a predetermined date. The building block of both approaches is the expectation that as service-based competition becomes less attractive over time, the entrant will gradually invest in its own network infrastructures.

Although sunset clauses and the ladder-of-investment theory have been embraced by many telecommunications regulators and organizations (ARCEP, 2007; EC, 2010b; ERG, 2005; ERG, 2006), the related literature provides mixed results about the effectiveness of each approach to make service-based and facilities-based competition complements in promoting both investments and competition. Avenali, Matteucci and Reverberi (2010) use a dynamic discrete choice model and assume that developing an alternative infrastructure requires both time and an installed base of consumers which implies that a period of service-based competition is a prerequisite for facilities-based competition in the next period. They find that a multi-period schedule where regulated access charges rise over time is critical to foster efficient infrastructure investments, whereas a sunset clause on regulation dilutes investment incentives. In addition, they point out that the regulatory commitment problem may affect the robustness of their main result. Thus, they propose that the access price should depend both on time and entry period in order to ensure that late entrants are provided with the same dynamic access conditions. In a more recent paper, Bourreau and Drouard (2010) use a general model of competition in order to study the impact of both a “replacement effect” and a “stepping stone effect” on an entrant’s incentives to invest in network upgrade. Thus, they allow an initial serviced-based period for the entrant to build its market share progressively. This implies that the entrant might have significant incentives to prolong the service-based competition phase in order to build a larger market share. They show that if facilities-based entry is a short-term (long-term) possibility, the replacement effect (the stepping stone effect) prevails, and hence, a phase of service-based competition delays (accelerates) facilities-based entry.

Therefore, as Bourreau, Doğan and Manant (2010) point out, a phase of service-based competition may be a necessary, but not a sufficient, condition to ensure that it will serve as a stepping stone to facilities-based entry if the replacement effect is neutralized. The authors also challenge another assumption of the ladder-of-investment theory which states that the regulator has the instrument to neutralize the replacement effect. They argue that although access prices that increase over time may neutralize the replacement effect, credibility of regulatory commitments and informational requirements raise several concerns about the successful implementation of this theory.

The effectiveness of the ladder-of-investment theory on encouraging new entrant operators to invest in their own access infrastructures has been studied not only theoretically but also empirically. Distaso, Lupi and Manenti (2009) use semi-annual data from 12 European countries (study period: January 2005-July 2007) and test the ladder-of-investment theory by looking at the link between the prices of wholesale access services and the relative growth rates of the three alternative inputs that can be used by new entrants to provide access and broadband services to end users: bitstream services, LLU services and their own networks. Although they point out that the policies adopted by NRAs are broadly consistent with the ladder-of-investment theory, their graphical results reveal that only few countries (France and Spain) have succeeded in encouraging the entrants to climb the investment ladder due to increasing access prices over time. In a more recent empirical study, Bacache, Bourreau and Gaudin (2011) use semi-annual data (from 2002 to 2009) covering incumbent and entrant fixed-broadband operators in 15 European member states in order to test the ladder-of-investment hypothesis. They find no statistically significant effect of the number of unbundled lines on the number of new access infrastructure lines built by entrants, which implies that there is no evidence in support of the ladder-of-investment hypothesis.

### *3.3. Access regulation and both firms' incentives to invest*

This strand of the literature on access pricing and investment incentives focuses on the effect of access prices on firms' incentives to invest in new access networks. This implies that the strategic impact of the investment decision of each firm on the other firms' investment decisions is taken into account. In particular, the related articles assume that there are two firms which have to decide if and when to deploy a new access network. It is obvious that this part of the literature does not discriminate between an incumbent and an entrant since either firm can invest first in a new network infrastructure. Thus, both firms are assumed to be symmetric.

In a dynamic context, firms may tend to preempt each other when there are significant first-mover advantages and delay investments when there are significant second-mover advantages. The former case triggers a race for investment, whereas the latter case leads to a waiting equilibrium. The regulator's goal is to set the access price at the level that incentivizes each firm to invest at the socially optimal time.

Hori and Mizuno (2006) use a model with stochastically growing demand in order to assess the impact of a uniform access price on a race of investment between two firms. They find that in the retail market an increase in the access price induces the leader to enter the market earlier and the follower to enter the market with access later or to build its bypass facility earlier. In addition, they also provide the conditions that induce the follower to enter the market by accessing the leader's network and then build its own network. Hori and Mizuno (2008) improve their previous work by comparing the impact of service-based and facilities-based competition on the timing of investments. They show that in service-based competition a follower enters the market earlier and builds a bypass later than in facilities-based competition. Concerning the leader's investment timing, they provide the conditions that determine the priority of the two competition schemes in terms of monopoly rents, access charges and degree of uncertainty.

In a more recent article, Vareda and Hoernig (2010) assume two-part access tariffs in which the usage price is used to maximize static efficiency and the fixed price to induce dynamic efficiency (i.e. to incentivize each firm to invest at the socially optimal time). They show that in a waiting equilibrium higher access prices make both firms to invest earlier. Considering the preemption equilibrium, they conclude that higher access prices have also a positive effect on the follower's investment timing but their impact on the leader's investment timing is ambiguous. Therefore, the first-best cannot be achieved with any given two-part access tariff. Thus, a sunset clause (respectively, a regulatory holiday) may lead to the first-best investment outcome if the follower's private investment incentives are small (respectively, high).

### *3.4. Discussion*

This section reviewed the articles that propose new regulatory approaches and then assess their effectiveness and efficiency implications. There are many useful regulatory implications that can be drawn by the analysis of the effect of the proposed approaches on firms' incentives to invest in NGA networks, as well as, on the subsequent competition level.

Firstly, although a regulatory holidays regime seems to induce the incumbent to deploy a broader NGA network earlier, it is inferior to risk-sharing and FDC regimes in terms of consumer surplus. However, regulatory holidays are superior to LRIC in terms of both investments and competition. In addition, a departure from uniform access prices cannot solve the dynamic consistency problem unless the investment cost is low compared to the investment benefits. Therefore, a departure from the permanent regulation of access at uniform cost-based prices is not adequate to promote both competition and investments in NGA networks by the incumbents. Secondly, although a phase of service-based competition may be a necessary, but not a sufficient, condition to ensure that it will serve as a stepping stone to facilities-based entry, an access price that increases over time does not always succeed in encouraging the entrants to climb the investment ladder.

It can thus be deduced that the related literature on the relationship between access regulation and investment incentives does not provide an optimal access pricing policy that promotes competition and encourages investments in NGA networks by incumbents and then entrants. In particular, the above results raise serious doubts about the effectiveness of the EC Recommendation concerning the permanent regulation of access at uniform cost-based prices and the implementation of the ladder-of-investment theory during the migration to a phase of facilities-based competition. However, the research articles study the impact of alternative regulatory approaches on either the incumbents' or the entrants' investment incentives without considering the strategic interaction between their investment decisions. On the contrary, the current regulatory framework in the European NGA market considers that the incumbent will invest first in new access infrastructures, while the entrants will gradually invest in their own bypass facilities. It is obvious that when the incumbent (respectively, the entrant) decides its optimal investment decision, it takes into account the optimal investment decision of the entrant (respectively, the incumbent). This implies that the disclosed access pricing policy should take into account the impact of access regulation on both firms' incentives to invest although such investment decisions are taken in a sequential order. The third literature strand takes into account such strategic reaction by allowing either an incumbent or an entrant to invest first in NGA networks. However, it provides mixed results concerning the impact of access prices on the leader's investment incentives even if a two-part access price is used to maximize both static and dynamic efficiency, as well as, it does not discriminate between a vertically integrated incumbent and a new entrant operator.

To best of authors' knowledge, the only paper that reflects the current regulatory framework in terms of the evolution of the regulatory goals over time is Vareda (2011). In particular, it considers a dynamic framework in which an incumbent chooses how much to upgrade the quality of its network and then an entrant, at each point in time, has the option to enter as a service-based competitor, by asking for access to the incumbent's network, or as a facilities-based competitor, by building a bypass network. He shows that when the regulator can *ex ante* commit to a two-part access tariff: (i) the entrant's investment in a bypass network is delayed with a higher incumbent's investment in quality; (ii) the possibility of investment in a bypass network by the entrant has a positive effect on the incumbent's incentive to upgrade quality; (iii) the effect of access prices on both incumbent and entrant firms' incentives to invest is ambiguous; and (iv) a welfare improving access tariff that could be designed by the regulator would be one where the access fee is increasing (decreasing) in quality if the incumbent's incentives are such that it under-invests (over-invests).

However, the work of Vareda (2011) not only uses a two-part access tariff (rather than a uniform access price), but also assumes that the access price is fixed over time (rather than reflecting a proportionate application of the ladder-of-investment principle). Therefore, his model fails to align with two of the four basic principles of the EC Recommendation.

On the contrary, this paper proposes an innovative approach that reflects the current regulatory framework in the European NGA market as described by the EC Recommendation (EC, 2010b). In particular, the proposed approach models the four basic principles of the current European regulatory framework and then assesses its effectiveness on inducing facilities-based competition over NGA networks. This implies that this paper can be included in the literature that departs from assessing the efficiency outcomes of the regulation of the copper access networks. It is shown that the proposed approach meets the current regulatory goals since it tackles the initial trade-off between encouraging the incumbents to invest in NGA networks and fostering competition, while it incentivizes the entrants to gradually climb the ladder-of-investment when the NGA investment is proven to be successful. Therefore, the proposed approach not only fills the gap between the reviewed literature and the current European regulatory framework, but also provides an effective migration path towards facilities-based competition over NGA networks.

## 4. A CDS approach

This section presents an innovative approach that aims to reflect the current regulatory framework in the European NGA market and then to assess its effectiveness on promoting competition and encouraging investments in NGA networks by both incumbents and entrants. In particular, the proposed approach is based on the basic principles governing a Credit Default Swap (CDS). Thus, this section initially provides a brief review of the basic features of a typical CDS contract. Then, it presents the proposed method, describes its implementation and discusses its impact on investment incentives and competition. It is shown that the proposed approach represents an effective way towards facilities-based competition over NGA networks.

### *4.1. Background*

A CDS contract is an agreement between two parties, the protection buyer and the protection seller. The first party to the contract, the protection buyer, wishes to insure himself against the possibility of default on a bond issued by a particular company. The company that has issued the bond is called the reference entity. The second party to the contract, the protection seller, is willing to bear the risk associated with default by the reference entity. The protection buyer of the CDS makes a series of payments (the CDS "premium" or "spread") to the protection seller and, in exchange, receives a payoff in the event of a default by the reference entity. If a default does not occur over the life of the contract, the contract expires at its maturity date, and hence, the protection seller does not make any payments to the protection buyer.[8]

The next section shows how the basic logic of a typical CDS contract can be applied in the telecommunications markets in order to induce facilities-based competition over new fibre access networks.

### *4.2. The model*

The proposed model assumes that there are two parties in the contract: the incumbent, which invests in NGA networks, and the regulator. They both agree on a business plan that allows the incumbent to recover[9] the investment in a nationwide NGA deployment (i.e. the deployment of an NGA network in every geographic area of the country) during a certain period of time. If the investment has not been recovered at the end of this period, the regulator commits itself that it will compensate the incumbent for the unrecovered part of the investment. After the end of this period, no regulatory remedies will be imposed to the incumbent (sunset clause). In exchange, the incumbent should make periodic payments to the regulator. However, the regulator chooses to subtract this amount from the payments that an access seeker makes to the incumbent in order to have access to the NGA networks. This implies that the incumbent does not pay a periodic premium to the regulator but it subtracts this amount from the access payments it receives. If, however, the investment has been recovered before the end of the clause, the regulator does not make any payment to the incumbent, the incumbent stops making indirect periodic payments to the access seeker and no remedies imposed to the incumbent. In such contract, the incumbent is the protection buyer and the regulator is the protection seller which will compensate the incumbent in the case of a default event (i.e. if the investment has not been recovered at the end of the predetermined period).

A very significant issue that should be further investigated is the content of the business plan. In particular, the incumbent and the regulator agree on a business plan that describes the time evolution of the basic parameters affecting the profitability of an NGA investment project. In other words, the business plan should assess the period of time required for the recovery of the investment under plausible assumptions about the main factors that affect the profitability of an investment in NGA networks. As it has already been stated above, the main factor that negatively affects the investment incentives in NGA networks is the uncertainty about the demand parameters, such as the diffusion of the new fibre-based services, the consumers' willingness-to-pay for such services and the

[8] For a detailed description of CDS contracts, see Longstaff, Mithal, and Neis (2005) and Arora, Gandhi, and Longstaff (2012).

[9] The exact interpretation of the term "investment recovery" depends on the particular financial methodology mutually agreed by the incumbent and the regulator in order to define the terms of the contract. Our main thesis is that this is an economic rather than an accounting term, and therefore, it is disconnected from any accounting terms (e.g. depreciation). We expect that the "investment recovery" will be based on discounted cash flows analysis (e.g. payback period based on discounted cash flows) with a fixed time horizon. Further discussion on the matter is beyond the scope of this paper, although we acknowledge that it provides an excellent field for future research.

market shares of the incumbent and the entrant. Thus, the business plan should clearly state how these parameters will evolve over time.

It is expected that the diffusion process will follow an S-shaped curve since the most known models used for such purposes provide an S-shaped curve describing technology diffusion among specific populations (Michalakelis, Varoutas and Sphicopoulos, 2008). At the initial stages of the diffusion process the potential buyers of the new product are the innovators and then the early adopters. Internal influences, such as word-of-mouth, and external influences, such as mass-media communication, facilitate the adoption of the new product by early majority, late majority and, finally, laggards. Therefore, the S-shaped curve reflects the fact that the migration from copper access networks to NGA networks is a slow process (Bourreau, Cambini and Hoernig, 2012).

However, according to Moore (1991) the most important phase in the diffusion process is the transition from the early adopters to early majority. The reason is that there are qualitative differences between these two groups, and hence, early adopters do not make good references for the early majority. Therefore, the whole investment may fail if the diffusion process does not cross this chasm. It is thus expected that the entrant will exploit the second-mover advantage of "wait-and-see" until the diffusion process cross this chasm. This implies that at the initial stages of the diffusion process the incumbent will serve almost the whole market. Hence, the incumbent takes the more interesting part of the market first and it becomes more difficult or costly (i.e. increases the switching cost) for the entrant to reach the market share needed for its profitability (WIK, 2009). This implies that if the diffusion process crosses this chasm, the entrant increases its market share but this increase is mainly due to new consumers rather than existing ones.

It is thus obvious that even if fibre access networks replace much of the existing copper access infrastructures, there will be a period during which both are in operation and are competing for customers. This implies that low access prices for the copper access networks increase the opportunity cost of the entrant's investment in NGA networks, making such investment less attractive, whereas low retail prices for the copper-based services discourage consumers to move from the old to the new technology unless the fibre-based services are priced sufficiently low as well (Bourreau, Cambini and Dogan, 2012). The former effect is widely known as a "replacement effect" and the latter as a "business migration" effect. The fundamental point is that higher access prices lead to higher retail prices. Therefore, a higher difference between fibre and copper access prices implies a higher difference between fibre and copper retail prices, which in turn, disincentivizes both entrant and consumers to move to the NGA networks. As a result, the relationship between the fibre and the copper access prices not only affects the providers' profits and investment incentives, but also the diffusion process of the new technology.[10]

Another significant source of uncertainty is related to the regulator's limited ability to make *ex ante* credible commitments. However, this model proposes that the contract commits the regulator to apply a certain policy during the whole

[10] See Bourreau, Cambini and Doğan (2013); Bourreau, Lupi and Manenti (2013); Brito, Pereira and Vareda (2012); Cambini and Silvestri (2012); Cave, Fournier and Shutova (2012); Inderst and Peitz (2012b); and Neumann and Vogelsang (2013) for a discussion about the impact of the regulation of the legacy network on the firms' investment incentives when the NGA market is left unregulated or when there is an interplay between the access prices of the two networks.

predetermined period. This policy, which concerns the derivation of the access pricing formula, as well as, its evolution over time, is known to the incumbent *ex ante*. As it has already been stated above, it is not optimal for the regulator to intervene in the market very often because it dilutes investment incentives. On the contrary, it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period. Thus, this model proposes an intermediate solution in which the regulator makes periodic reviews at a predetermined period. In each periodic review the regulator may increase or decrease the access price according to certain rules that are described in the contract and presented in the following section. It can thus be deduced that the incumbent invests in NGA networks under regulatory certainty.

### *4.3. Implementation*

At time $t=0$ the incumbent and the regulator agree on a business plan that allows the former to have recovered the investment in NGA networks at time $t=T$ with a given probability. Or, in other words, they estimate the probability of default ($P_0$), as well as, the corresponding unrecovered part of the investment ($X_0$) at the end of the predetermined period. The subscript “0” denotes the values of the parameters $P_t$ and $X_t$, $t \in [0,T]$, at the time that the estimation takes place (i.e. $t=0$ in this case). Based on the estimated values of $X_0$ and $P_0$, they assess the amount of the periodic payments ($K_0$) that the incumbent should make to the regulator. This implies that if the estimated demand parameters at $t=0$ coincide with the actual ones during the whole predetermined period *T*, the total amount of the periodic payments will be $TK_0$.[11] However, the regulator chooses not to receive such payments but to subtract this amount from the access payments. Therefore, the reduced access payments that the entrant will finally make to the incumbent from $t=0$ to $t=T$ are given by:

$$AP_{0-T} = W_C \sum_{t=0}^{t=T} Q_t^E - TK_0 \tag{1}$$

or

$$AP_{0-T} = (W_C - R_o) \sum_{t=0}^{t=T} Q_t^E \tag{2}$$

where $W_C$ denotes the cost-based access price, $Q_t^E$ represents the estimated number of consumers served by the entrant at time *t*, $t \in [0,T]$, and $R_0$ is a regulatory parameter such that

$$R_0 \sum_{t=0}^{t=T} Q_t^E = TK_0 \tag{3}$$

[11] In fact, $X_0$ denotes the estimation at $t=0$ for the discounted unrecovered part of the investment, and hence, the estimation at $t=0$ for the total amount of the discounted periodic payments is given by: $\sum_{t=0}^{t=T} \frac{K_0}{(1+r)^t}$, where $r$ denotes the interest rate.. However, throughout this paper, we have assumed, for simplicity, that $r=0$ since the abstraction of the time-value-of-money does not change the results qualitatively.

Therefore, the access price that the entrant pays to the incumbent during the *T* years is given by $W_0 = (W_C - R_o)$. It is thus obvious that the access payments that an entrant pays to the incumbent for one period $t \in [0,T]$ are derived by multiplying the access price with the number of the entrant's subscriber at period *t*. The sum of these payments from $t=0$ to $t=T$ yields the total access payments that the entrant pays to the incumbent in order to have access to the NGA networks for the whole predetermined period *T*. If the estimated demand parameters at $t=0$ coincide with the actual ones during the whole predetermined period *T*, then the initial regulatory policy will lead to the recovery of the NGA investment at time $t=T$. Since the main factor that affects the profitability of an NGA investment is the demand for the new fibre-based services, it is expected that the cumulative recovery of the investment will also follow an S-shaped pattern as depicted in figure 1.

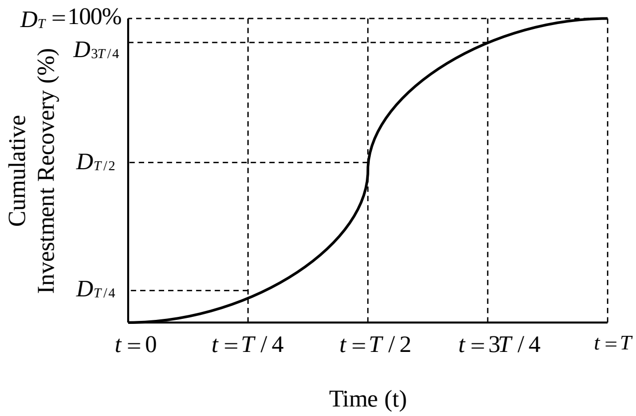


**Figure 1.** Cumulative recovery of the NGA investment

However, since the periodic payments are closely related to the possibility of default, it can be deduced that the amount of such payments may vary over time. The reason is that although the business plan forecasts the evolution of the demand parameters over time, it is uncertain whether the actual demand will coincide with the estimated one. For example, even if the diffusion process will follow an S-shaped curve, the time at which the saturation level will be achieved may deviate from the estimated one. As a result, it is also uncertain whether the investment will have been recovered at the end of the predetermined period. Since it is not optimal for the regulator to make *ex ante* commitments for unreasonably short or long regulatory periods, the proposed approach states that the regulator makes periodic reviews at predetermined periods in order to correct potential distortions due to any deviation from the estimated parameters. Thus, the business plan clearly states that the regulator will make periodic reviews every *T/m* years. In the example presented in figure 1, the regulator makes periodic reviews every *T/4* years. In addition, the proposed model states that in each review, the regulator changes the access price only if the initial estimation (made at $t=0$) for the cumulative recovery at the time of the review, $D_t$, deviates from the actual cumulative recovery more than *x%*. The exact percentage of *x* is mutually agreed by the incumbent and the regulator.

However, the most significant issue is how the regulator changes the access price in each periodic review. The reason is that a marginal change in the access price will significantly affect the incumbent's profits, the entrant's investment incentives, as well as, the competition level. The basic principle governing the change in the access price is the estimation of the periodic payments made from the protection buyer to the protection seller in a CDS contract. In each periodic review, the regulator should examine whether the cumulative recovery of the NGA investment is higher or lower than the initially estimated one by more than *x%*. Therefore, three cases should be studied. In the first case, the investment is successful since the actual cumulative recovery is higher than the initially estimated one by more than *x%* (upside case). In the second case, the investment is not successful since the actual cumulative recovery is lower than the initially estimated one by more than *x%* (downside case). In the last case, the difference between the actual and the initially estimated cumulative recovery is less than *x%* (base case).

### *4.3.1 The upside case*

Let's assume that in the first regulatory review ($t = T/4$) the actual cumulative recovery is higher than the initially estimated one ($D_{T/4}$) by more than *x%*, i.e. $(D_{T/4}^{actual} - D_{T/4})/D_{T/4} > x\%$. Therefore, the regulator should intervene in the access market in order to review the access price. In this case, the probability of default decreases since it is more probable that the investment will have been recovered before the end of the predetermined period $T$. Hence, the value of the probability of default at $t = T/4$ is lower than its value at $t = 0$ (i.e. $P_{T/4} < P_0$). In addition, the estimated unrecovered part of the investment ($X_{T/4}$) is also lower than the initially estimated one ($X_0$). As a result, the periodic payments that the incumbent will make to the regulator from $t = T/4$ until $t = T$ should be lower than the initially estimated ones (i.e. $K_{T/4} < K_0$). Thus, the regulator should set $R_{T/4}$ at the level that makes the following equation hold:

$$R_{T/4} \sum_{t=(T/4)+1}^{t=T} Q_t^E = (T - T/4)K_{T/4} \qquad (4)$$

In other words, the regulator should assess the value of $R_{T/4}$ that leads the left side of Eq. (4) to decrease as much as the decrease caused by the upside case to the right side of Eq. (4). Firstly, note that a decrease in the regulatory parameter $R_t$ leads to an increase in the access price. Indeed, the access price that the entrant will pay to the incumbent from $t = T/4$ until $t = T$ is given by $W_{T/4} = (W_C - R_{T/4})$. Obviously, this access price is higher than $W_0$ since $R_{T/4} < R_0$. A higher access price causes the entrant's market share to decrease and the incumbent's market share to increase. Secondly, a higher access price leads to a higher retail price for the fibre-based services. Therefore, the difference between the retail prices of the copper and the NGA networks increases, thereby making the latter less attractive for consumers. This result mitigates the diffusion process and negatively affects the demand faced by each provider. It is thus obvious that when the regulator decreases the regulatory parameter $R_t$, the entrant's consumer base decreases due to the aforementioned reasons.[12] Therefore, a

[12] The value of *x* should be high enough in order to ensure that the annual periodic payments which the incumbent will make to the regulator $(K_t)$ are substantially decreased (or increased in the downside case). The reason is that if the decrease in the entrant's consumer base is much higher than the decrease in the annual periodic payments, then a higher $R_t$ may be required in order to make Eq. (4) hold. However, this is in contrast with the fact that the decrease in the entrant's consumer base stems from a decrease in $R_t$. It is thus obvious that the access price

proper decrease in $R_t$ ensures that the decrease in the amount subtracted from the access payments (left side of Eq. (4)) is equal to the decrease in the amount that the incumbent should have paid to the regulator (right side of Eq. (4)).[13]

The most interesting result of this regulatory policy is that it encourages the entrant to invest in its own facilities. Indeed, an increase in the access price of the NGA networks raises the entrant's variable cost, decreases its market share and its profits, and hence, makes fibre unbundling less attractive for the entrant. In conclusion, the proposed approach provides the entrant with incentives to climb the ladder-of-investment in each upside case. As the entrant gradually invests in its own network, it becomes more effective competitor. As a result, the retail price decreases which, in turn, enhances the diffusion process. Therefore, this approach increases the probability of a successive upside case in the next regulatory review. It is obvious that this approach will be implemented as long as the actual cumulative diffusion is higher than the initially estimated ones (i.e. $D_{T/4}$, $D_{T/2}$, $D_{3T/4}$) by more than *x%*.

The opponents of this approach may argue that the incumbent does not have any incentives to invest under such a regulatory approach since its profits stoke the recovery of the investment, whereas the entrant makes positive profits by exploiting the second-mover advantages. However, we should keep in mind that as soon as the investment has been recovered, the sunset clause ends. Therefore, the incumbent pursues to accelerate the diffusion process in order to recover the investment earlier and then reap the benefits of being the first-mover (i.e. its high market share consisting of consumers with high willingness-to-pay).

### *4.3.2 The downside case*

Now, let's discuss the case of downside. Assume, for example, that the actual cumulative recovery is lower than the estimated one ($D_{T/4}$) by more than *x%*, i.e. $(D_{T/4} - D_{T/4}^{actual}) / D_{T/4} > x\%$. Therefore, the regulator should review the access price. In this case the estimation made at $t = T/4$ for the probability of default, as well as, for the unrecovered part of the investment are higher than the initially estimated ones. Hence, $P_{T/4} > P_0$ and $X_{T/4} > X_0$. As a result, the periodic payments that the incumbent will make to the regulator from $t = T/4$ until $t = T$ should be higher than the initially estimated ones (i.e. $K_{T/4} > K_0$). Contrary to the upside case, the regulatory policy that makes Eq. (4) hold is to increase the regulatory parameter $R_t$.

The reason is that an increase in $R_t$ has a twofold impact on the entrant's consumer base. Firstly, the access price decreases, and hence, the entrant's market share increases. Indeed, the access price that the entrant will pay to the incumbent from $t = T/4$ until $t = T$ is given by $W_{T/4} = (W_C - R_{T/4})$ and is lower than $W_0$ since $R_{T/4} > R_0$. Secondly, a lower access price for the NGA networks leads

should be reviewed when the actual diffusion is significantly deviated from the initially estimated one (i.e. either in upside or downside cases).

[13] Of course, an increase in the regulatory parameter $R_t$ causes the opposite results. In this case, the left side of Eq. (4) is higher than the respective right side, which implies that such a regulatory decision does not reflect the reduction (due to the upside case) in the amount that the incumbent should have paid to the regulator.

to a lower retail price for the fibre-based services. Therefore, the difference between the retail prices of the copper and the NGA networks decreases, thereby making the latter more attractive for consumers. This result positively affects the demand faced by each provider and enhances the diffusion process. Therefore, an increase in the regulatory parameter $R_t$ leads the entrant's consumer base to increase. As a result, a proper increase in $R_t$ ensures that the increase in the amount of the left side of Eq. (4) is equal to the increase in the amount that the incumbent should have paid to the regulator given by the right side of Eq. (4).

Of course, since the access price decreases, the entrant does not have any incentives to invest in its own facilities. However, in this case, the regulator's goal is to increase the total demand rather than incentivizing the entrant to invest in NGA networks. The reason is that the entrant invests in NGA networks only when the NGA investment is successful. Therefore, the regulator should first promote the success of the NGA investment and then encourage the entrant to invest in its own facilities. It is obvious that the proposed approach fulfills in enhancing the diffusion process since a lower access price facilitates service-based competition over NGA networks, as well as, the new access network becomes more attractive for consumers. Therefore, it is expected that in the next regulatory review the diffusion process (and by extension the cumulative recovery) will coincide with the initially estimated one.

The opponents of the proposed approach may also argue that a lower access price decreases the incumbent's profits. Therefore, the incumbent would not have signed the modified CDS contract. However, recall that the probability of a downside is higher at the initial stages of the diffusion process and that the incumbent's goal is to recover the NGA investment as soon as possible in order to exploit the first-mover advantages and maximize its profits after the end of the sunset clause. This implies that the incumbent is willing to sacrifice some short-run profits for maximizing its long-run profits. A basic prerequisite for the early recovery of the NGA investment is the acceleration of the diffusion process and especially the crossing of the chasm at its initial stages. In addition, high access prices are more profitable for the incumbent in the upside case (i.e. when the entrant has a significant market share). On the contrary, in the downside case, a high access price deteriorates the entrant's position in the market, thus making the magnitude of such an access price insignificant and the success of the NGA investment more uncertain.

However, it should be noted that in the downside cases the proposed approach is more effective at the initial stages of the diffusion process rather than at its final stages. The reason is that the potential increase in the adoption rate due to a decrease in the access price is limited as the diffusion process approaches its saturation level. However, it is expected that the proposed model can handle the high probability of a downside at the initial stages of the diffusion process by increasing the adoption rate, and hence, leading to an upside at the following regulatory reviews.

### *4.3.3 The base case*

In the base case, the difference between the actual cumulative recovery and the initially estimated one is lower than *x%*, i.e. $\left|D_{T/4}-D_{T/4}^{actual}\right|/D_{T/4}<x\%$. This implies that the initially estimated demand parameters are very close to the actual ones,

and hence, the actual diffusion process is almost as expected. Therefore, the regulator does not change the access price until the next regulatory review.

### *4.3.4 A numerical example*

This section presents a numerical example of the implementation of the CDS approach in order to show its impact on competition and investment incentives under an upside, a downside and a base case. In addition, it presents the competition and investment outcomes when the NGA investment is recovered before, after and at the predetermined period.

Assume a hypothetical country of 10 million citizens. The regulator and the incumbent agree on a business plan which forecasts the diffusion process of the new fibre-based services for the next 12 years. The diffusion process follows the S-shaped pattern of figure 1 and approaches its saturation level of 50% in the 12th year. In addition, the cumulative recovery at $t \in [0,T]$ is assumed to be twice the diffusion of the fibre-based services at time *t*. Therefore, the cumulative recovery follows an S-shaped pattern as depicted in figure 2.

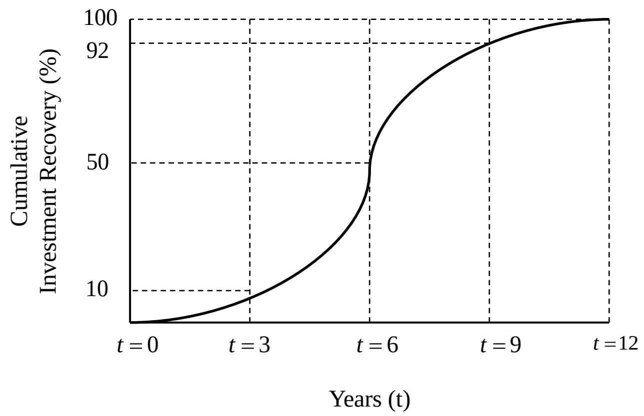


**Figure 2.** Example of the cumulative recovery of the NGA investment

It is further assumed that the incumbent's initial market share of 95% decreases by 5% each year. Based on these estimations, the regulator and the incumbent agree that the NGA investment level will have been fully recovered after *T*=12 years with a certain probability. Table 1 presents the estimated annual cumulative recovery (%), as well as, the modified estimations made in *t*=3 and *t*=6 due to a downside and an upside case, respectively.

**Table1. Estimated and actual cumulative recovery**

| **Year (*t*)** | **Initially (made at *t*=0) estimated cumulative recovery** | **Modified estimated cumulative recovery made at *t*=3** | **Modified estimated cumulative recovery made at *t*=6** |
|---|---|---|---|
| 0 | 0 | 0* | 0* |
| 1 | 2 | 2* | 2* |
| 2 | 6 | 4* | 4* |
| 3 | 10 | 6* | 6* |

| | | | |
|---|---|---|---|
| 4 | 16 | 18 | 24* |
| 5 | 28 | 32 | 40* |
| 6 | 50 | 50 | 66* |
| 7 | 66 | 66 | 72 |
| 8 | 76 | 76 | 78 |
| 9 | 82 | 82 | 82 |
| 10 | 90 | 90 | 90 |
| 11 | 96 | 96 | 96 |
| 12 | 100 | 100 | 100 |
| * indicates the actual cumulative recovery at $t \in [0,T]$ | | | |

However, if the NGA investment has not been recovered after 12 years, the regulator will pay to the incumbent the unrecovered part of the investment. The investment cost of a nationwide NGA deployment is assumed to amount to $F = 10^{10}$€.

The initial estimation for the unrecovered part of the investment ($X_0$) and the probability of default ($p_0$) leads to an initial estimation of the annual periodic payments, e.g. $K_0 = 5\times10^6$€. This implies that if the initial assumptions coincide with the actual ones during the whole regulatory period, the investment will have been recovered after 12 years, whereas the incumbent will have paid to the regulator $TK_0 = 60\times10^6$€. As it has been already mentioned above, the regulator does not receive this amount, but he subtracts it from the cost-based access payments. The cost-based access price is given by $w_C = c(1+WACC)$, where $c$ represents the cost of providing the access to the NGA networks and *WACC* is the weighted average cost of capital of the incumbent. This implies that if $c = 10$€ and *WACC=10%,* the cost-based access price is 11€. In addition, the value of $R_0$ that makes equation (3) hold is 5,358€ since $\sum_{t=0}^{t=12} Q_t^E = 11.197.044$. Therefore, the access price is 11-5,358= 5,642€. According to Equation (2), the total access payments are 63.173.722€.

However, the regulator should review the access price every 3 years in order to ensure that the diffusion process and the subsequent cumulative recovery will result in the recovery of the NGA investment after 12 years. If the difference between the actual cumulative recovery and the initially estimated one is more than *x*=10%, then the regulator changes the access price.

Let's assume that the time lag of the diffusion process is one year, which implies that in the first regulatory review (*t*=3) the cumulative recovery is 6% and the saturation level in *t*=12 will be 96%. In this case, *x*>10%, and hence, the regulator should change the access price. The reason is that in the downside case the periodic payments that the incumbent should make to the regulator increase. Assume, for example, that $K_3 = 8\times10^6$€, which implies that $(T-3)K_3 = 72\times10^6$€. Therefore, the regulator should increase the regulatory parameter $R_t$ such that the product of $R_3$ and the subsequent increased consumer base of the entrant is equal to $(T-3)K_3$. Hence, the incumbent's market share decreases with a higher rate, e.g. 7% each year. In addition, the decrease in the access price results in a decrease in the retail price of the fibre-based services which, in turn, enhances the diffusion process. It is thus expected that in the next regulatory reviews the actual penetration levels will coincide with the initially estimated ones. This implies that the cumulative entrant's subscribers from *t*=4 to *t*=12 are 13.359.117, and hence, the value of $R_3$ that makes Eq. (4) hold is $R_3 = 5{,}389$. In this case, the access price is $W_3 = 11 - 5{,}389 = 5{,}611$.

Now, let's examine an upside case. Assume that in the next regulatory review (*t*=6) the cumulative recovery is 66%, and hence, the NGA investment will have been recovered at *t*=11. As a result, *x*>10% which implies that the regulator should change the access price. The reason is that in the upside case the annual periodic payments that the incumbent should make to the regulator decrease. Assume, for example, that $K_6 = 3\times10^6$€, which implies that $(11-6)K_6 = 15\times10^6$€. Therefore, the regulator should decrease the regulatory parameter $R_t$ such that the product of $R_6$ and the subsequent decreased consumer base of the entrant is equal to $(T-6)K_6$. A decrease in $R_t$ has a twofold effect on the entrant's consumer base. Firstly, the access price increases which, in turn, leads the entrant's market share to increase with a lower rate (or, equivalently, the incumbent's market share decreases with a lower rate, for example 3%). Secondly, the increase in the access price results in an increase in the retail price of the fibre-based services which, in turn, negatively affects the diffusion process. It is thus expected that in the next regulatory reviews the actual penetration levels will coincide with the initially estimated ones and the investment will have been recovered at *t*=12. Therefore, the cumulative entrant's subscribers from *t*=7 to *t*=12 are 9.995.395, and hence, the value of $R_6$ that makes Eq. (4) hold is $R_6 = 1{,}507$. In this case, the access price is $W_6 = 11 - 1{,}507 = 9{,}493$.

It seems that the proposed approach hinders the diffusion process by increasing the retail price through the increase in the access price. However, the increase in the access price, as well as, the decrease in the entrant's market share will probably cause the entrant to climb the investment ladder. This expectation is enhanced by the fact that there was an upside in the diffusion process, which triggers the regulatory intervention in the access market, and hence, the investment seems to be profitable. As the entrant gradually invests in its own facilities, it becomes more effective competitor. This, in turn, decreases the retail prices and boosts the diffusion process. Hence, the probability of a successive upside case in the next regulatory review increases. As a result, the proposed approach is consistent with the ladder-of-investment theory when the investment is proven to be successful.

Now, assume that in the next regulatory review (*t*=9) the cumulative recovery is as expected, i.e. 82%. In this case, the regulator does not change the access price set at the previous regulatory review since it is expected that the reviewed access price at *t*=6 will lead to the recovery of the NGA investment at *t*=12.

### *4.4. The end of the clause*

Three different cases concerning the review of the access price has been already examined and discussed. However, the success of the proposed approach is related with its ability to lead the NGA investment to be recovered (at least) at a predetermined period. Thus, a further discrimination between three cases according to whether the NGA investment is recovered earlier, later or at the predetermined period is needed.

When the NGA investment has been fully recovered at *t*=*T*, the regulator does not make any further payment to the incumbent, the latter stops making indirect periodic payments to the entrant and no regulatory remedies are imposed to the incumbent. This implies that the incumbent is free to set the access price to the recovered NGA networks. If the NGA investment has been fully recovered at *t*=*T* due to successive downside cases or because the initially estimated cumulative recovery has been very close to the actual one, then the entrant would have probably established a significantly high customer base. It is thus expected that the entrant will invest in its own facilities in order to be active in the market as soon as the clause ends unless the incumbent prices the access too low in order to avoid intense facilities-based competition.

Furthermore, if the NGA investment has been fully recovered at *t*=*T* due to successive upside cases, then increasing access prices would have led to intense facilities-based competition. It is expected that the end of the clause does not significantly affect the entrant's investment incentives since the entrant would have already climbed many rungs of the investment ladder. This implies that the new entrant will be based on its own infrastructure rather than on incumbent's one for serving its consumers, thereby rendering the unregulated access price of limited significance. In these cases, the NGA investment may have been also recovered before the predetermined period.

Although we believe that the proposed approach will eventually lead to the recovery of the NGA investment at $t=T$ or even earlier, we cannot exclude the possibility that the NGA investment would have not been recovered at the end of the predetermined period *T*. Assume that the actual cumulative recovery at $t=T$ is lower than the initially estimated one ($D_T = 100\%$). In this case, the default event occurs and the regulator compensates the incumbent for the unrecovered part of the NGA investment which is given by $(100\% - D_T^{actual})(investment\cos t)$. Using the numerical example of section 4.3.4, we assume that at *t*=12 the CDS approach has fulfilled in recovering only a part of the investment cost. For instance, if the actual cumulative recovery of the investment at *t*=12 is 70%, then the regulator should compensate the incumbent for the unrecovered part which is $(100\% - D_T^{actual})F = (30\times10^{10})/100 = 3\times10^9$.

The difference $(D_T - D_T^{actual})$, which is closely related to the upside or downside cases in the previous regulatory reviews, significantly affects the entrant's investment incentives and the subsequent competition level after the end of the clause. The reason is that after that time no regulatory remedies will be imposed to the incumbent, and hence, the entrant will not have access to the incumbent's NGA networks at regulated prices. One should further discriminate between three cases according to the difference $(D_T - D_T^{actual})$.

Firstly, if in the previous regulatory reviews there were successive upside cases, this difference should be low enough and the diffusion process should have reached its saturation level. Hence, the entrant would have already climbed many rungs of the investment ladder and the end of the clause will incentivize the entrant to be a facilities-based competitor.

Secondly, if in the previous regulatory reviews there were successive downside or base cases which have led the entrant to build a critical market share due to low access prices, then the difference $(D_T - D_T^{actual})$ is expected to be low enough, and hence, the entrant will probably invest in its own facilities in order to continue being active in the market.

However, if the low access prices have failed to induce the entrant to increase its market share due to the low demand for the new fibre-based services, then the difference would be high enough, the incumbent's market share would be also low and the proposed approach would fail to promote facilities-based competition over NGA networks.

It is obvious that regardless of the unrecovered part of the investment, public funds will be used in order to compensate the incumbent. Therefore, one could argue that the proposed CDS approach privatizes profits and socializes losses by allowing the regulator to bear part of the investment risk. For this reason, the next section discusses the economic rationale of the proposed approach.

### *4.5 The economic rationale of the CDS approach*

Although the regulatory intervention at predetermined periods ensures that the cumulative recovery process will not deviate significantly from the initially estimated one, the possibility of a default event cannot be excluded. The existence of such probability implies that the proposed CDS approach may privatize profits and socialize losses by allowing the regulator to bear part of the investment risk. In other words, public funds may be used for compensating private investments in NGA networks. Therefore, the regulator should compare the costs and the benefits of bearing part of the investment risk from a social perspective.[14] Obviously, the social cost of the CDS approach is the amount of compensating the incumbent in the case that the NGA investment has not been recovered after *T* years. If social benefits outweigh social costs, then the regulator is willing to bear part of the investment risk.

According to the EC (2010b) "*the EU single market for electronic communications services, and in particular the development of very high-speed broadband services, is key to creating economic growth and achieving the goals of the Europe 2020 strategy. The fundamental role of telecommunications and broadband deployment in terms of EU investment, job creation and overall economic recovery was notably highlighted by the European Council in the conclusions of its March 2009 meeting*". In addition, referring to work undertaken by the OECD (2009), the EC (2010c) states that "*the cost savings in just four sectors of economy (transport, health, electricity and education) would justify the construction of a national fibre-to-the-home (FTTH) network*". It is thus obvious that "*the social benefits from investment in digital infrastructures by far exceed the private incentive for investment*" (EC, 2011). The reason is that like many infrastructure investments, NGA networks may create positive spill-over effects that are not captured in any individual user's willingness-to-pay. This implies a clear public policy case for governments to facilitate the roll out of NGA networks

[14] Although in the economic terminology social surplus includes both industry profits and consumer surplus, we use the term social surplus as meaning consumer surplus (i.e. excluding private costs and benefits) in order to emphasize that the socialization of the losses is referred to the part of the losses which are funded by the consumers (not the firms) in the NGA market.

by reducing the risk for the investor (DotEcon, 2012). Therefore, when there are significant social benefits stemming from NGA investments but the private investment incentives are weak, the regulator should bear part of the investment risk in order to encourage the wide deployment of NGA networks. This view is also expressed in the Digital Agenda for Europe (EC, 2010a): "*without strong public intervention there is a risk of a sub-optimal outcome, with fast broadband networks concentrated in a few high-density zones with significant entry costs and high prices. The spill-over benefits created by such networks for the economy and the society justify public policies guaranteeing universal broadband coverage with increasing speeds*".

Recent empirical studies have tried to quantify the positive impact of investing in broadband infrastructures on the main economic and social indices, with the research focus shifting towards the impact of higher speed services. Considering that broadband penetration may be endogenous to the growth process, Czernich, Falck, Kretschmer and Woessmann (2011) estimate the effect of broadband infrastructure investments on economic growth in the panel of OECD countries in 1996–2007. They find that after a country had introduced broadband, GDP per capita was 2.7–3.9% higher on average than before its introduction. In terms of subsequent diffusion, an increase in the broadband penetration rate by 10 percentage points raised annual growth in per capita GDP by 0.9–1.5 percentage points. Furthermore, Katz, Vaterlaus, Zenhäusern and Suter (2010) estimate the impact of broadband infrastructure investments on German employment and economic output, following the government's National Broadband Strategy that extends through 2014 and the subsequent ultra-broadband evolution from 2015 to 2020. They find that a total investment of close to 36 billion euros in broadband infrastructures would generate a total of approximately 1 million incremental jobs and an additional value added of 33.4 billion euros, while network externalities would result in an additional 137.5 billion euros. In total, this results in 170.9 billion euros of additional GDP (0.60% GDP growth) in Germany.

It can thus be concluded that broadband connectivity is widely accepted as strategically important not only because of its ability to accelerate the contribution of information and communications technology (ICT) to economic growth (Teppayayon and Bohlin, 2010), but also because network investments are potentially important targets of public investment during downturns as a way to increase demand and employment (Reynolds, 2009). These results have encouraged national government around the world to be actively involved in the deployment of regional or nationwide NGA networks by adopting various subsidization strategies (Cave and Hatta, 2009; DotEcon, 2012; Kenny and Kenny, 2011; Ruhle, Brusic, Kittl and Ehrler, 2011). Such supply-side policies exert a positive impact on penetration and economic growth at the initial stages of the diffusion process, thus justifying their use in the deployment of NGA networks (Belloc, Nicita, Rossi, 2012). These initiatives imply that social benefits not only exceed the private incentive for investments, but also the potential social costs. Therefore, governments are willing to use public funds in order to either deploy state-owned NGA networks or subsidy private investments in such networks, although there is a risk of socializing losses. It is thus obvious that the expected social benefits from the deployment of NGA networks are much greater than the part of the deployment cost which is financed by public funds.

In the proposed CDS approach the social costs are even lower since the regulator compensates the incumbent only for the unrecovered part of the NGA investment and only in the case that the investment has not been recovered after a predetermined period. Unlike the governments' subsidization strategies which use the public funds *ex ante* (and thus regardless of the success of the investment), the proposed approach correlates the amount of the public funds used with the success of the investment. In particular, the more successful the investment is, the lower the amount of the public funds used for financing the NGA investment. Therefore, the expected social costs, which *ex post* stem from the CDS approach, are lower than the social costs of *ex ante* (partially or wholly) subsidizing a given NGA investment. As a result, the difference between social benefits and costs is even higher, which means that the adoption of the CDS approach is clearly justified in social terms.

The basic mechanism used by the CDS approach to reduce (or even to annihilate) the amount of public funds used to compensate the incumbent is to make the new entrant receive a subsidy equal to the fictitious costs of the credit default insurance. From the incumbent's point of view such subsidy is irrelevant since it does not affect its profits (ceteris paribus). Indeed, the incumbent considers the entrant's subsidy as cost either if it takes the form of the credit default insurance or the form of a reduction in the access payments. Obviously, the entrant's profits increase but the variation in the access price, which depends on the success of the NGA investment, makes the entrant an effective service-based competitor in the downside cases and an effective facilities-based competitor in the upside cases. This result has a twofold implication. Firstly, not only the incumbent forgoes revenues from the access market in order to minimize the investment risk, but also it forgoes revenues from the retail market due to the intensification of competition. Therefore, the proposed CDS approach works pretty much in the same way as the financial CDS contract in which a protection buyer minimizes its investment risk by forgoing some of its future profits.[15] Secondly, the proposed CDS approach maximizes the potential efficiency outcomes taking into account the existing conditions in the NGA market. Of course, these efficiency outcomes have a strong positive impact on consumer surplus. In other words, the indirect subsidization of the entrant increases consumer surplus, and hence, social benefits outweigh social costs.

It should be noted that this result does not necessarily imply that the proposed CDS approach maximizes social welfare. In fact, it provides a theoretical approach to encourage the deployment of a nationwide NGA network (i.e. maximize the potential investment outcome in terms of geographic coverage) with the ambition that such deployment will finally reflect the socially desirable choice as reflecting in an effective migration path towards facilities-based competition over NGA networks.

### *4.6 Implementation issues and limitations*

The proposed model describes a feasible way to initially encourage the incumbent to invest in new fibre-based access networks and then to induce facilities-based competition over NGA networks. The access pricing scheme ensures that the access is provided at cost-based prices including a risk premium. In the proposed model, the regulator not only eliminates the uncertainty of the NGA investment, but also the uncertainty of the usefulness of the risk

[15] The Appendix provides an example of a financial CDS contract and relates the outcomes with the application of the CDS approach in the NGA market.

premium.[16] For this reason, the risk premium is subtracted from the cost-based access price. This definition implies that the cost-based access price of the NGA networks represents the highest access charge that the entrant may pay to the incumbent. However, we should keep in mind that a cost-based access price does not necessarily implies a low access cost since: (i) the cost of providing the access to the NGA networks is much higher than the respective level of copper networks, and (ii) the level of the cost-based access price depends on the applied costing methodologies (DotEcon, 2012). Furthermore, the implementation of the CDS approach focuses on the impact of a change in the access price (regardless of its nominal value) on the recovery of the NGA investment and on the entrant's incentives to invest in its own NGA network. Therefore, the proposed CDS approach can be also used in the cases where the initial access price is higher or lower than the cost-based access price.

In addition, the flexibility of the regulator to review the risk premium following certain rules tackles the additional trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare. The rules under which the regulator review the access price ensure that such price increases over time as long as the investment is successful. This implies that the proposed model reflects an application of the ladder-of-investment theory, and hence, it succeeds in inducing facilities-based competition over NGA networks. It is thus obvious that the success of NGA investments is a necessary, but not a sufficient, condition for the application of the ladder-of-investment theory. The reason is that even if the investment is successful, a decreasing access price reflecting the lower demand uncertainty increases the entrant's opportunity cost of investing in its own facilities, and thus dilutes the entrant's investment incentives. From the above analysis it can be deduced that the proposed approach is aligned with the four basic principles of the current regulatory framework in the European NGA market.

Hitherto we have limited our analysis to the case in which one investor has undertaken a nationwide NGA deployment. However, it is widely known that both market and geographic characteristics affect the profitability of an NGA investment. In particular, potential investors are willing to deploy fibre access networks in the areas which are characterized by high population density and high GDP per capita. The former factor ensures low investment cost, whereas the latter is positively correlated with the consumers' willingness-to-pay for the new fibre-based services. This implies that both market and geographic conditions have already led to differences in the degree of NGA deployment not only across countries, but also across areas within a given country. In these cases, the CDS approach can be applied to encourage the deployment of NGA networks in the rest geographic areas either in an integrated or in a fragmented way. In the former case, the regulator and an investor agree on a business plan that allows a single investor to recover the NGA investment in the rest geographic areas. In the latter case, the regulator agrees on many business plans with different investors each of them being willing to invest in a specific geographic area in a country.

The variety of local market and geographic conditions is reflected in the resulted regulatory remedies of the CDS approach. For instance, in the more densely populated areas the deployment of NGA networks is more profitable from an

[16] According to ETNO (2008), the risk premium reimburses the incumbent only when the investment is successful. Therefore, in the downside cases the usefulness of the risk premium is of limited importance.

investor's perspective, and hence, the CDS approach results in higher access prices and shorter period of access regulation. On the contrary, in the less densely populated areas, the probability of default is higher, and hence, the CDS approach results in lower access prices which promotes entry by alternative operators in order to boost the diffusion process. In addition, the existence of a strong cable industry in a country implies that the nationwide NGA deployment creates a facilities-based competition between the investor and the cable company. This result has a positive effect on consumers' willingness-to-pay, and therefore, to the diffusion process. Put differently, successive upside cases are expected which, in turn, lead to high access prices. This outcome is socially desirable since facilities-based competition is preferred than service-based competition which is promoted by low access prices. It can thus be deduced that the proposed CDS approach is scalable and consistent with the view of BEREC (2011) concerning the different regulatory treatment across countries or geographic areas when there are significant national or regional differences in terms of population density, willingness-to-pay, inter platform competition etc.

Although the proposed CDS approach seems to facilitate the deployment of fibre-based access networks and the gradual migration from service-based to facilities-based competition over NGA networks, there are some limitations that should be further investigated.

Firstly, the proposed approach does not take into account the impact of the bargaining power of the two parties in the contract on the periodically reviewed access price. In particular, the proposed approach implicitly assumes that both parties have the same bargaining power which does not change during the predetermined period. It is obvious that since the bargaining power of either the regulator or the incumbent may change as a result of the implementation of the CDS approach, the impact of such change on the access prices, and thus, on the cumulative recovery process should be further explored.

Secondly, the major shortcoming of the proposed approach is the assumption that the regulator has full information about the evolution of the main demand and cost parameters. However, potential investors have an incentive to misrepresent information, such as to increase the total cost of the investment and to shorten the reasonable period for the recovery of the investment in order to be over-compensated for the unrecovered part of the investment and then reap the benefits of being the first-mover. It is thus obvious that there are many informational requirements, and hence, regulators should oblige the investor to provide information about its business operation and its network structure. Both BEREC (2011) and the EC recommendation (EC, 2010b) envision such transparency, especially for the technical characteristics and the geographical location of the investor's network. This implies that regulators should incentivize operators to provide the actual information about the access networks. In particular, regulators should crosscheck the provided information by applying various costing methodologies, cooperate with audit companies in order to retrieve financial statements and intensify quality and competition tests. When it is found that the provided information significantly deviates from the actual one, then the regulator should penalize the investor for misrepresenting information.[17] Therefore, if both the probability of finding such misrepresentation and the

[17] We would like to thank Professor Martin Cave for a private conversation about this issue at the 19th ITS Biennial Conference.

subsequent penalty are high, then the investor does not have significant incentives to misrepresent information.

Although such a regulatory treatment enables the regulators to properly assess the actual investment cost, it also makes regulatory agencies act as operators which are willing to invest in NGA network. This argument is enhanced by the proposed approach in which regulatory agencies are actively involved in business decisions concerning the expected profitability of deploying an NGA network taking into account the cost and the timing of such investments, the risk of the specific investment project and the periodic payments that correspond to the default event. Put differently, regulators should expertise in business and management decisions which implies a slippery slope from setting the rules under which incumbents and entrants operate toward micro-management of investments.

## 5. Conclusions

This paper initially showed that the regulatory policy which aims to stimulate competition in the market by facilitating entry of alternative operators, promotes static efficiency at the cost of dynamic efficiency. Thus, it reviewed the EC Recommendation on regulated access to NGA (EC, 2010b) which provides the NRAs with guidelines for tackling this trade-off, as well as, the research articles which propose new regulatory approaches that may promote both static efficiency and investments in NGA networks. It was found that: (i) there is no consensus about the optimal regulatory policy that promotes competition and encourages investments in NGA networks; and (ii) the reviewed research articles are not consistent with the current regulatory framework in the European NGA market as described by the EC Recommendation in terms of both the evolution of the regulatory goals over time (i.e. encourage the incumbents to invest in new fibre-based access networks without distorting service-based competition, and then encourage the access seekers to invest in their own fibre infrastructures) and the proposed regulatory settings (i.e. the characteristics of the access pricing formula, the evolution of the access price over time and the provision of regulatory certainty).

Therefore, the goal of this paper was twofold. In particular, it aimed to develop a new regulatory approach which reflects the current European NGA framework and tackles the trade-off between promoting competition and encouraging investments. It was shown that under plausible assumptions the proposed approach, which is based on the basic principles governing a Credit Default Swap (CDS), tackles the initial trade-off between encouraging the incumbent to invest in NGA networks and fostering competition, while it incentivizes the entrant to gradually climb the ladder-of-investment. This implies that the proposed approach represents an effective way towards facilities-based competition over NGA networks.

The main innovation of this paper was the application of a pure financial tool to the field of regulatory economics. For this reason, the migration from copper access networks to NGA networks was studied under quite general but plausible assumptions. For example, the proposed CDS approach was based on the assumption that the cumulative recovery process is analogous to the diffusion process of the fibre-based services. Although this is a plausible assumption, a more rigorous techno-economic analysis, which takes into account all the factors that affect each provider's profits, is needed. In addition, numerical calculations of the evolution of the probability of default and its impact on access prices, investment incentives and competition are also needed.

It is thus obvious that this paper also aims to trigger a fruitful open discussion about its implementation limitations and its effectiveness on inducing facilities-based competition over NGA networks. The starting point of this discussion should unambiguously be the need for an extensive review of the existing legislation regarding the legal authorities of the regulatory agencies. The current framework seems to provide legal restrictions on regulators to sign such CDS contracts that may result in the subsidization of the investors by using public funds. Therefore, the question of whether regulatory agencies should have the jurisdiction to sign such contracts deserves more attention and requires further investigation.

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## Appendix

The model works pretty much in the same way as the CDS protection bought in the financial market. Let's assume a simplified example in which a financial institution A invests 10M € in an investment grade corporate bond with annual coupon payment of 6% and 10 years to maturity. At the day of purchase, the corporate bond is downgraded to a speculative rating. To avoid selling on loss, the financial institution decides to enter into CDS with a financial institution B, with a 3% spread paid annual on face amount of 10M €. The following happens:

- The financial institution A receives each year 6% coupon payment on 10M € i.e. 600.000€.
- The financial institution A pays each year CDS premium of 3% on 10M € i.e. 300.000€ to the financial institution B.
- In the case of default the financial institution A receives from the financial institution B 10M €.
- In the case of no default the financial institution A receives the face amount of 10M € from the issuer of the bond.

What happens in the above case is that the financial institution A has no risk at all no matter what the outcome of the investment is. It only gives up a premium of 300.000€, which can be seen from our model's perspective as the part that incumbent forgoes when agreeing to consider the regulatory parameter $R_t$ in the access pricing model.

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# APPENDIX B

The research towards the completion of this thesis led to the publication of six original articles that are not at the centre of the literature studying the optimal regulatory intervention in each migration phase during the evolution of the telecommunications networks. Appendix B quotes these articles as they have been originally published in refereed international journals or including in the proceedings of refereed international conferences.

**D. Katsianis, T. Rokkas, I. Neokosmidis, M. Tselekounis, D. Varoutas, I. Zacharopoulos, and A. Bartzoudi, "Risks associated with next generation access networks investment scenarios,"** ***IEEE Network*****, vol. 26, no. 4, pp. 11–17, 2012.**

# Risks associated with Next Generation Access networks investment scenarios

D. Katsianis, Th. Rokkas, I. Neokosmidis, M. Tselekounis, D. Varoutas, I. Zacharopoulos, and A. Bartzoudi

Abstract— The deployment of Next Generation Access Networks (NGA) is investigated from technical, regulatory and investment perspectives. A brief review of the possible network architectures and deployment scenarios of NGA is provided. Risk calculations of these NGA scenarios are performed based on a fully detailed techno-economic model. Furthermore, the effectiveness of the European Commission's Recommendation on regulated access to NGA aiming to tackle the regulatory trade-off between encouraging investments and promoting competition is discussed.

*Index Terms*— Investment risk, Next Generation Access Networks, Techno-economics, Engineering Management

## I. INTRODUCTION

The last years, there is an explosive growth of internet in terms of both the number of users and the transmitted volume of data. It is interesting to note that the aggregate volume of data circulated in the internet is expected to increase with an annual growth of 30% for the next years [1] while the lowest demanded capacity by the end-users is doubled almost every two years [2]. Therefore, there is an increasing need for bandwidth resulting in new access methods.

In the case of access networks based on copper, there are several inherent technical and physical limitations setting barriers to performance such as the maximum distance, the bandwidth, the number of concurrent customers etc. On the other hand, access networks based on optical fibers are the only future proof solution capable to handle the future demands [3], since the transmission capabilities of fiber are theoretically unlimited providing high data rates, low loss and low distortion.

According to European Commission "Next generation access networks (NGAs) mean wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network" [4]. Therefore, according to the EC two technologies are assumed as NGA i.e. FTTCab and FTTH/B.

There has been an extensive discussion regarding NGA during the recent years, however the high cost of the development of NGA, in combination with the high uncertainties mainly on demand and revenues (that induces corresponding uncertainty to investment returns) and restrain service providers from investing in NGA [5]. In this perspective, this paper aims to identify, quantify, evaluate and discuss the risk characteristics of the NGA.

The rest of the paper is organized as follows: initially the regulation framework regarding NGA is presented in section II. Technological options are illustrated in Section III. Section IV reports regulatory options related to NGA and Section V discusses the modeling assumptions. Results regarding the total risk are presented in section V. Some concluding remarks are given in Section VI.

## II. NGA REGULATION & POLICY FRAMEWORK

Various policies are discussed and have been followed in order to overcome the uncertainty related to the deployment of NGA networks. USA provided regulatory holiday to two (geographically separated) operators in order to build their NGA networks, while other countries (mainly in Asia) have preferred the state-aid solution towards the NGA investing firms.

The European Commission (EC) issued a Recommendation on regulated access to NGA [4] in order to provide National Regulatory Authorities (NRA) with guidelines for tackling the trade-off between fostering competition and promoting investments with regard to NGA.

In particular, the EC Recommendation is in accordance with the overall Europe's regulation regime since it proposes that the access fees in any of wholesale products should be based on a cost-based form.

This holds for any wholesale access product irrespective whether it falls in the scope of the market for wholesale physical network infrastructure (usually named as Market #4) or the wholesale broadband access (Market #5).

However, the EC Recommendation introduced the term of risk premium that should be included in the calculation of the costs of the wholesale access fees in order to compensate the investor for any additional and quantifiable risks incurred when investing in NGA networks. The principles of this premium calculation are described in detail in a special annex of the EC Recommendation. More specifically, this premium should reflect: “(i) uncertainty relating to retail and wholesale demand; (ii) uncertainty relating to the costs of deployment, civil engineering works and managerial execution; (iii) uncertainty relating to technological progress; (iv) uncertainty relating to market dynamics and the evolving competitive situation, such as the degree of infrastructure-based and/or cable competition; and (v) macroeconomic uncertainty.”. It is worth mentioning that the incumbent operators usually claim that there is another risk factor named regulatory risk which is related to the regulator’s limited ability to make ex-ante credible commitments.

## III. NGA ARCHITECTURES SET BY THE EC RECOMMENDATION

Although several architectures of access networks have already been proposed, including wireless ones, the EC proposed only fixed ones and always based on fiber [7]. In this paper four alternative architectures are modeled and studied. One is FTTC with VDSL and the other three are FTTH.

### A. Fiber to the Curb (FTTC) with VDSL

Regarding the FTTC architecture, the path from the service provider’s Point of Presence (POP) to the intermediate node (street cabinet) that serves an entire neighborhood exclusively consists of optical fiber (Fig. 1). A switch (Digital Subscriber Line Access Multiplexer – DSLAM), placed on the street cabinet, is connected to the POP of the service provider via a fiber or a pair of optical fibers carrying the aggregated traffic from the neighborhood traffic usually through Gigabit Ethernet. The access of each end user up to the switch of the street cabinet is realized using the standard copper cables used for the PSTN network and Very High Speed DSL (VDSL technology over copper cables. Depending on both the technology and the distance, the end users experience symmetric or asymmetric data rates of up 100Mbps, depending on the copper length.

The FTTC architecture provides to the incumbent the advantage to connect its subscribers to existing copper cable infrastructure in the first mile. Additionally, it has lower capital requirements since the NGA investment is done only in part of the access network. However, it has limited time frame since there is a need for capacity doubling every two years.

### B. Fiber to the Home (FTTH) scenarios

According to the Fiber to the Home architecture, the path from the service provider’s point of presence (POP) to the end user exclusively consists of optical fiber (Fig. 1). The fiber is terminated inside the home or the workplace of the end user. Therefore, each device at the subscriber premises is connected through a dedicated optical fiber to a switch port located at POP or to the optical splitter which in turn connects to the POP via a single feeder fiber.

Three FTTH technologies are mature enough to use in an NGA investment. The choice of each technology depends on the type of the transmitted service, the infrastructure cost, the existing infrastructure and future plans towards new technologies.

1. Gigabit Passive Optical Network (GPON)

In passive optical networks, each customer is connected to the optical network via a passive optical splitter. The advantages of FTTH PON [8] are related to: (a) the use of purely passive components between the central office and the end user (b) less requirements for fiber investment in the network segment LEX-outdoor cabinet (c) less space requirements inside the LEX since less fibers and thinner trenches are terminated to LEX. The above issues lead to lower maintenance and operational costs. However, there are a number of disadvantages related to the GPON: (a) since a number of users (up to 16-32 or at maximum 64) share the capacity traveling over just one fiber, there are limitations on the maximum capacity per user. (b) due to the above, since there is congestion among the various users, it is mandatory to have resource protocols to run between LEX and users as well as to have more advanced CPEs (such as burst receivers) compared simper CPEs required in case of pure point-to-point connections (c) the unbundling is limited by physical network resources.

The Optical Line Termination (OLT) is the basic element of the network. It is usually placed at the Central Office (CO) and is the driving force of FTTH systems. The Optical Network Units (ONUs) are placed close to the end user. ONUs are connected to the OLT through optical fiber without using intermediate active components (Fig. 1).

2. Point-To-Point (P2P)

Active Ethernet, also known as Ethernet Switched Optical Network (ESON) or Point to Point (P2P) network, provides a dedicated optical fiber from the outdoor active equipment to each end user. In the case of P2P, operation, management and maintenance as well as the calculation of the power budget are greatly simplified due to the existence of this dedicated fiber. Core switch, aggregation switch and the ONT are the main components of a P2P network (Fig. 1). Beyond the advantage of P2P that offers almost maximum capacity (100 Mbps or 1 Gbps signal in a 100 BaseFX or 1000 BaseLX) to each end-user, there is a main disadvantage: it requires the maximum invested capital since a fiber pair is dedicated to each user. Therefore large space for the ODFs inside LEX should be available such as in the case of copper networks and the trenches (especially closer to the LEX) are expected to be wider (more complex and costly).

3. Point to Point Ethernet P2PE

In P2PE scenario a first aggregation switch is located in the cabinet between the central office and the user premises. The architecture is similar to the one of GPON with the difference that there is active equipment in the cabinet (Fig. 1). This technology seems to accommodate the pros and cons of all other technologies: (a) requires power in the field (b) might offer higher capacity per user that FTTC/VDSL and GPON but in any case lower than the maximum provided by the pure P2P technology. The specific technology could be the migration of a FTTC/VDSL network since the power could be already available or of a GPON network since fiber is available and only changes to outdoor cabinet should be performed.

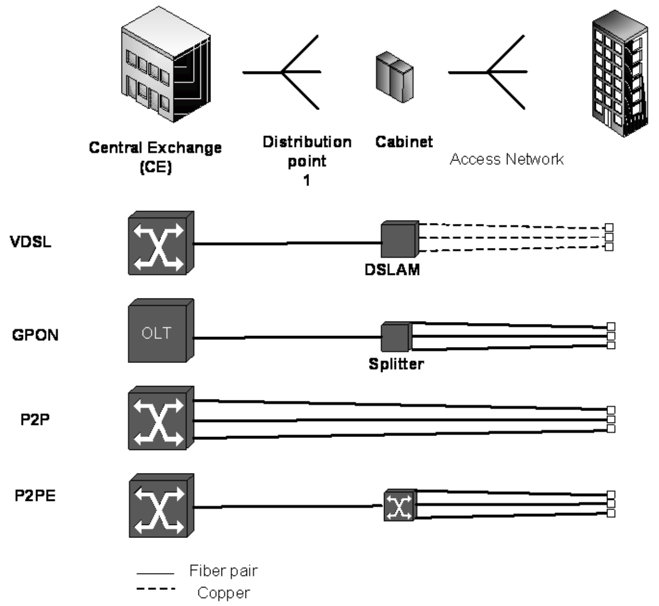


FIGURE 1. EXAMINED ARCHITECTURES

## IV. NGA REGULATORY OPTIONS

### A. The main NGA risk factor: The risk of future demand for new fiber-based services

Demand and penetration are the main factors which cause risks related to NGA investments [9]. The higher the penetration of the potential customer base is, the higher the profitability of the investment becomes. Moreover, if the penetration does not reach the critical mass that is required for the creation of the new fiber-based services market, the NGA investment may not even be profitable at all.

There are three factors that influence the penetration of the new fiber-based services. First, the existence of competing NGA fiber network platforms, such as cable networks, increases the risk of both penetration and investor's market share. In particular, the higher the degree of facilities-based competition is, the higher the risk of both penetration and investor's market share becomes. Secondly, the co-existence of a remaining copper network DSL platform and a new fiber NGA platform increases the risk of the future demand for the new fiber-based services. In particular, the higher the migration period from copper-based services towards NGA-based services, the higher the risk of the penetration of the new NGA-based services. Last, but not least, the risk of sufficient Willingness to Pay (WTP) increases the risk of future demand for new fiber-based services).

Although, it is expected that the WTP for the new services will be higher than the WTP for the existing services since the former offer improved characteristics, such as better quality and higher data rate, it is doubtful that this increase in consumers' WTP will be sufficient for recovering the high investment cost.

### B. Regulatory policy

Regulator’s goal is twofold. First, it aims to encourage investments in order to promote innovation and market growth and, second, to foster competition in the retail market in order to ensure lower prices, better quality and higher social welfare. Taking into account that the EC recommendation sets a predetermined framework to follow but in any case regulatory holiday is not a desirable option, a European regulator has many different means in order to affect both investments and competition. Initially, the regulator should decide about the regulatory regime (e.g. access levels and corresponding wholesale access products, etc). According to the above decision, the regulator should then decide about specific parameters of the regulatory policy, such as the regulatory period (i.e. the interval between two reviews of the regulatory policy), the risk premium and other complementary regulatory options (e.g. adoption of risk sharing schemes, adoption of a transparent framework for the migration path from copper to fiber-based networks, etc).

The impact of each decision on investment and competition varies significantly. Some regulators are in favor on encouraging investments than fostering competition. Therefore, there is a trade-off between promoting investments and fostering competition. In any case, regulatory certainty is expected to promote investment in NGA. This requires regulator’s ex ante commitment for its decisions for a long period of the economic lifetime of an NGA investment but especially for the first and most crucial time period.

In the following analysis, it has been assumed that NRAs adopt and implement the EC Recommendation on regulated access to NGA. Therefore, the access to wholesale physical network infrastructure (Market 4), as well as, the wholesale broadband access (Market 5) should be mandated and cost-oriented. In addition, NRAs should be able to calculate and include a higher risk premium to reflect any additional and quantifiable investment risk incurred by the investor. This risk premium should be incorporated into the Weighted Average Cost of Capital (WACC) calculation for setting the price of access to the unbundled copper loop.

## V. TECHNO-ECONOMIC MODEL

### A. Risk calculation

The tool used in this study is the ECOSYS techno-economic tool which has been used in the evaluations of various wireless and wireline access technologies. The application of the model relies on its database, where the cost figures of the various network components are kept and are constantly updated from data gathered from the biggest European telecommunication companies. Further information can be found in [5]. The outputs of this model are: (a) the investments undertaken by the incumbent (b) the unit costs of the various retail and wholesale products (c) the risk premium associated to the specific investment

In order to make the above calculations the tool creates a modeled NGA network in a bottom-up (BU) long run incremental cost (LRIC) approach. BU stands for the approach of creating the appropriate scale/footprint of the network that the foreseen demand requires. Therefore proper dimensioning rules are followed to tailor the necessary type and volume of components to the expected services’ demand. LRIC approach means mainly that the only the NGA increment is modeled and no other network that might be complement to NGA (for example such as a leased line core network). For the first two of the above outputs, the volumes of the necessary components are calculated based on the demand and the unit costs of the various necessary components are used. For the last calculation which is the risk premium, it is necessary to account future cash flows according to the Recommendation. Therefore, assumptions for the revenues and their evolution over time, should be occurred.

By combining the revenues and expenditures sides, namely service revenues, investments, operating costs and general economic inputs (e.g. discount rate, tax rate), the tool calculates the results necessary for Discounted Cash Flow (DCF) analysis such as cash flows, Net Present Values (NPV), Internal Rate of Return (IRR), payback period and other economic figure of merits for the NGA investor. The risk factor, which is the main output parameter that will be presented in the following sections, is defined as the difference the standard (traditional) WACC minus the IRR of the NGA project following discussion in [9].

*Total NGA risk factor = Traditionally defined operator WACC minus the IRR of the NGA project*

This is called as total risk and it should not be misinterpreted to the risk premium reported in the Recommendation. The total risk refers to how much higher should the IRR of an NGA project be than the traditional WACC of an operator (that is based on all other operator's activities which are mainly traditional ones like voice, access, leased lines, etc.). In the following paragraphs, the total risk that the operator will be exposed if made the decision to implement a NGA, will be calculated and discussed, for the 4 scenarios studied.

## B. Modeling Assumptions

The model calculates all the necessary costs and revenues that the incumbent will face if it takes the decision to implement a NGA in an area that is served from one central office. Each area according to its density (customers/square km) is characterized as Dense Urban (DU), Urban (U) or Suburban (S), and for each area there are different assumption concerning the number of buildings and other geographical parameters that are presented in Table I.

**TABLE I: AREA CHARACTERISTICS**

| Area | Buildings per cabinet | Floors per building | Apartments per building | Density threshold (customers/km$^2$) |
|---|---|---|---|---|
| DU | 20 | 4 | 4 | 9000 |
| U | 32 | 4 | 2 | 1000 |
| S | 36 | 2 | 1 | 500 |

The incumbent offers services both to retail and wholesale broadband market. The project's study period is set to 20 years, beginning at 2011. For the first 10 years of the analysis full dimensioning of costs and revenues is performed. However, for the next ten years the following assumptions have been used, since it is very difficult to make long-term estimations and prognoses. The cost of investments was assumed that will remain at the same levels as in the last three years (7th - 10th year) of the analysis. For both revenues and running costs a linear estimation was performed taking into account again the last three years.

The WACC pre tax has been assumed as 10,5% (defined as a mean value among European incumbent operators) and it has also been used as the discount factor in the DCF analysis.

As far as the broadband products offered and the forecasted revenues the following assumptions has been used. Two retail products (lower and higher) offered by the NGA investor were modeled (30Mbps and 50Mbps for FTTC and 75Mbps and 100Mbps for FTTH scenarios). Two corresponding wholesale broadband products (wholesale broadband access, WBA or bitstream) were assumed to offer to the access seekers. For simplicity reasons their price was set at retail-minus of 20%, but it is possible to set them at cost-oriented level (with or without risk premium). Moreover, wholesale physical access products were assumed priced at cost-oriented level without premium . The mix of WBA and physical access products is 50%-50%. It is assumed that the NGA investor has an initial NGA retail market share of 90% which at the 10th year has been reduced to 70% due to competitive pressure by the access seekers. The revenue has been assumed almost constant during the time period examined. This is consistent to the approach followed by almost all operators and almost in all countries to keep the same revenue and offer higher speed to the consumers or make some offers over the time. A 2% tariff yearly reduction has been assumed due to these offers.

## VI. RESULTS

As a first step in the analysis, a total number of ten geographic areas have been selected with 320.000 potential subscribers in total. Three of them were characterized as DU, five as U and the rest three as S. The model calculated the total risk for the case that the incumbent operator decides to deploy the same architecture solution to all the areas for all 4 architectures.

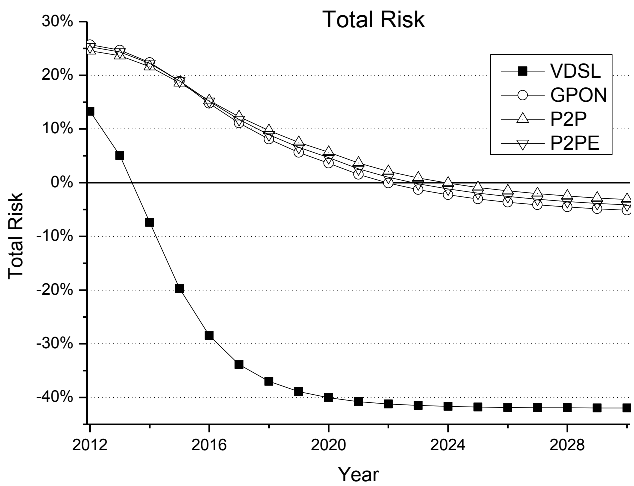


FIGURE 2. TOTAL RISK FOR ALL ARCHITECTURES

Negative total risk means that the IRR of the NGA project itself is higher than the traditionally calculated WACC of the operator-investor, thus the NGA project can be considered as profitable as the current (traditional) investment. In other words negative or even small positive but close to zero values indicate that the risk of the specific scenario is rather minimal. Obviously, for the 3 FTTH scenarios this profitability can be observed only after many years of operation, verifying all worldwide discussion about the risks entailed to the FTTH/NGA investment. The launching period of FTTH/NGA operation is the most crucial since it is characterized by high risks, due to all parameters already discussed and mainly due to low penetration, adoption or demand. Therefore, it is verified how strategic the role of the regulator is during this first NGA operation interval. The regulatory decisions taken ex-ante (i.e. during this first NGA operation interval) should be the optimum in order to avoid altering this risk profile and perhaps towards worsening it.

As it can be seen at Fig. 2 the three FTTH architectures have more or less the same risk and the FTTC scenario is significantly better. It is worth mentioning that FTTC/VDSL2 has much less risk than the other ones due to its lower capital demanded to invest (mainly less trenching). Therefore, the frequent comment posed by incumbent operators that the FTTC/VDSL2 entails significant risks loses its validity especially when compared to the other technologies. It is worth mentioning that profitability of this FTTC/VDSL scenario is achieved a less than 5 year time interval. This is attributed mainly to high urban nature of the selected mix of areas modeled. Risks of FTTC/VDSL2 investment are considerably reduced in dense-urban and urban areas.

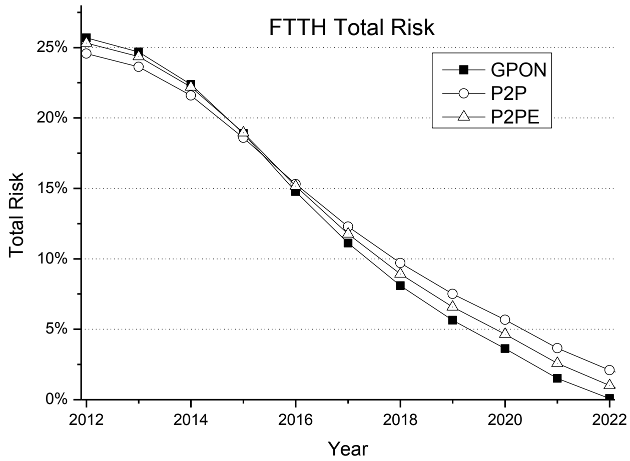


FIGURE 3. TOTAL RISK FOR FTTH ARCHITECTURES

Fig. 3 focuses on FTTH architectures only, while the study period is limited at only the first 10 years. It is worth mentioning that risk levels of the three FTTH technologies are more or less the same though their different pros/cons profiles. This indicates that a more detailed analysis should be followed and special attention should be paid regarding the cost assumptions for each one of the GPON, P2P, P2PE technologies. Beyond FTTCab/VDSL2 which has in general less risk, there should be careful calculation for risk associated to FTTH technologies. In case of any FTTH technology for a time interval of the investment at 10 years, a minor but positive value less that 3% is occurring (Fig 3). This can be interpreted as profitable case within a 10-years period, even for those risky investments and despite the usual utility-like investments which are profitable beyond the time period of 20 years. However, this medium term profitability can be secured when a number of contributing factors hold cumulatively: (a) a relative revenue (i.e. ARPU-Average Revenue Per User) stability over time during this time interval i.e. not price war situations among access providers and access seekers (b) roll-out cost reduction by strategies like co-investment among access providers, access seekers and possibly other parties, state/municipality facilitation etc. (c) regulatory stability and close monitoring towards relaxing in case of pertaining risk profile (d) demand aggregation by state-aid or even facilitation.

Especially the regulators face a big dilemma for those FTTH cases. If they follow the Recommendation they have to calculate a risk factor which should be probably high. This factor must be used to reward the NGA investor and as a result this risk premium would raise the unit cost i.e. the tariffs of both retail and wholesale services. If these tariffs are set initially at high prices then the demand for these prices should face even more risk and might lead the NGA investment to a total sunk cost with fewer possibilities to profitability. If they don't follow the Recommendation regarding the cost-orientation basis (which is not easy to prove to the EC) then alternative schemes should be invented. For example: (a) the retail tariffs can be set by the operators according to their own commercial policies which might accept short term losses towards gaining more customer base or in an anchor-pricing form [10] and (b) wholesale prices can be set in retail-minus basis or other alternatives that are indicated by the European Regulatory Framework and common practices. However, these strategies are easy to lead to price wars which in the end of the day might push all operators to limited profitability (or even negative).

At the next step, a new scenario was created in which the incumbent implements a mixed roll-out scenario deploying FTTH/GPON in the three DU areas and FTTC/VDSL in the rest seven areas. With this solution the incumbent avoids using the costly FTTH technology in areas with low customer density and reuses part of the already installed copper network. The total risk for the incumbent-investor was calculated and the results are presented at Fig. 4.

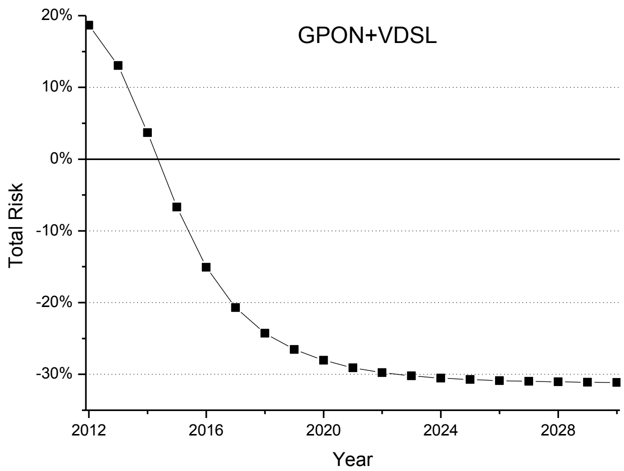


FIGURE 4. TOTAL RISK FOR GPON+VDSL SCENARIO

As expected, the risk calculated falls between the cases of pure FTTH-GPON and VDSL scenarios. The risk of this investment scheme is significantly lower than the GPON one. The total risk seems to be close to zero in about four years time, indicating higher possibility to project profitability. This indicates that the optimum strategy by the investing operator shouldn't follow just one technology. On contrary, and as expected, in areas with low expected demand and/or customer purchasing power risky investments should avoided. Regulators' challenges in these cases are related towards ensuring access of all consumers and access seekers to all technologies/areas perhaps by geographical remedies.

Finally, in order to further clarify the parameters that affect the total risk a sensitivity analysis was made in the risk value of the above modeled scenario at the 10th year. The impact of some critical parameters (such as the revenues, the penetration and the cost for digging and constructing the network, not the equipment cost) was examined. In sensitivity analysis each parameter is changed in order to study the impact that the changes in each parameter have to the output variable (while the others remain constant). The results are presented at Fig. 5. Each parameter was changed within an interval of ±20% of their initially assumed values. The most important impact is that of the revenue followed by the penetration and finally the digging cost. It should be denoted that if the case was purely FTTH the impact of the digging cost would be significantly higher. This result regarding the impact of revenue to the risk confirms our previous discussion in Fig.3 about the important role of ARPU stability over time in an NGA environment. Any that could contribute towards avoidance of price war in NGA environment would be welcomed measure (regulatory or not, like state-aid etc.). Price wars have been a common practice in many sector including traditional telecoms; however price wars in NGA era would likely push/force every involved actor to market exit.

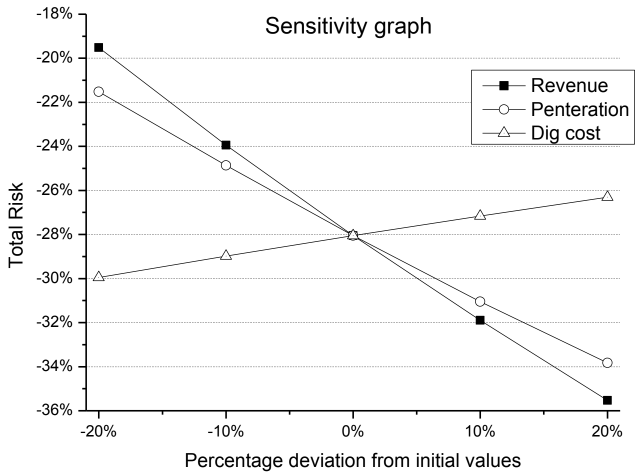


FIGURE 5. SENSITIVITY GRAPH FOR GPON+VDSL SCENARIO

## VII. CONCLUSIONS

The risk profile of NGA investments has been quantified, analysed and discussed under different scenarios for the first time according to our knowledge. It seems that FTTC/VDSL2 has not significant risk profile due to its high re-use of significant portion of existing copper PSTN network. This investment is expected to be profitable in less than five years time interval though the claims of some incumbent operators for high risk of this technology as well.

All FTTH technologies have more or less the same risk profile but further examination is required. The risk profile of all is very high during the launching period but reduces to almost zero after about a decade. This means that the NGA investment has lower duration than utility-like investments but its risk is high especially in first years of operation.

Taking into account the above, it is crucial for all involved parties (operators, regulators, EC, States etc.) to understand all these risk factors of the NGA investment itself. The NGA risk forces all to cooperate in order to minimize it, otherwise there will be no NGA at all. The access seekers should not based only on regulator's remedies to keep their operations in an NGA environment. Even in the worst case for NGA investor regime (cost-orientation with premium) the access-seekers have to pay high access price. Therefore, they should not follow a price war policy in the retail market.

The NGA investor should benefit from a risk premium but this premium should not be too high otherwise it will kill its retail price too. In a NGA environment the operators cannot continue their policy that they have used to in the current business environment. On contrary they should share their risk. The EC recommendation offers a number of tools but unfortunately some of these (like cost-orientation combined to risk-premium) possibly does not lead to risk relax, while some others do facilitate the risk sharing.

Credibly the regulators should be in position to accept a long term NGA policy with close monitoring and perhaps other policies/tools beyond standard cost-orientation approach (at least for a temporal/transition period).

The EC that issued the NGA recommendation must understand there are many practical details resulting from what described in this recommendation. The cost-orientation combined with premium is leading to high wholesale access prices. If retail prices are kept below these wholesale access prices in order to attract customer base then the EC should accept at least for short term period that predatory pricing is a temporal sacrifice towards the well understood NGA risk. Unfortunately, this NGA recommendation does not consider the details in such cases, and perhaps could deserve further review. But, fortunately the EC NGA recommendation depicts that risk sharing is accepted. The risk sharing via co-investment or other schemes should be the basis for the NGA operators (investors and access-seekers)

The Member States may play the most important role since they can make higher or lower grade interventions towards facilitation of NGA deployment. For example, these interventions could include: proposals for state-aid measures regarding NGA deployment, facilitation measures such as demand stimulation/subsidization, network facilitation such as relaxation on the rights of way, etc. Some of the above NGA risks could be waived (at least partially) after a successfully designed measure initiated by a State or an arm of it.

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# NGA Investments: A departure from the existing cost and demand structure assumptions

**By**

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## Abstract

The two most significant factors that affect the deployment of Next Generation Access (NGA) networks are the cost of the investment and the expected demand for the new fibre-based services. The related literature is based on very simplified assumptions regarding cost and demand structures.

In particular, the investment cost is assumed to be increasing and convex reflecting the fact that fibre deployment becomes marginally more expensive as it is extended to rural, less populated areas. In addition, the demand for the new fibre-based services is estimated by assuming that a certain level of NGA investment leads all consumers to equally increase their willingness to pay for such services.

This article contributes to the emerging research on the investment in access infrastructures. In particular, the assumptions about cost and demand structures are modified in order to capture the access networks' underlying morphology complexity and the consumers' socioeconomic characteristics, respectively. Firstly, an empirical analysis is conducted for the 100 major municipal departments from urban to rural in Greece. Their street network data are analyzed as the basis of the NGA installation combining GIS technology and Graph Theory techniques and hence the main cost-drivers are derived. Using regression analysis a real-data-based cost function is obtained. Secondly, a novel model that takes into account socioeconomic characteristics affecting the impact of a certain level of NGA investment on consumers' willingness to pay is developed. The Pareto consumer distribution is used to reflect the greater (lower) positive impact of NGA investments on the willingness to pay of the consumers who live in more (less) populated areas.

The comparison of the existing models with the ones developed in this paper shows that: (i) the cost function used in the existing models always underestimates the investment cost of the higher populated areas and overestimates the investment cost of the lower populated areas; (ii) the demand for the new fibre-based services is higher under the proposed than the existing approach; and (iii) the level of NGA investment chosen by the investor is always much higher under the proposed than the existing approach.

## 1. Introduction

During the last decade, the number of internet users, as well as, the capacity they demand have increased dramatically. As a result, the increasing transmitted volume of data made the traditional access copper networks incapable of providing end-users with the demanded bandwidth. On the contrary, access networks based on optical fibre are the only future proof solution capable to handle the future demands (Shumate, 2008), since the transmission capabilities of fibre are theoretically unlimited providing high data rates, low loss and low distortion. Such fibre-based access networks are widely known as Next Generation Access (NGA) networks. According to European Commission "NGA networks mean wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGA networks are the result of an upgrade of an already existing copper or coaxial access network" (EC, 2010a).

However, not only technical reasons but also economic ones make the need for investments in NGA networks imperative. In particular, it is found that investments in broadband infrastructure have an undisputable positive effect on economic growth and broadband diffusion (Czernich, Falck, Kretschmer and Woessmann, 2011; Katz, Vaterlaus, Zenhäusern and Suter, 2010; Reynolds, 2009). These results partially interpret why national governments rank among their top priorities the encouragement of investments in NGA networks. The US government's National Broadband Plan (FCC, 2010) and the European Commission's Digital Agenda for Europe (EC, 2010b) are examples of these perceived political priorities for the diffusion of broadband infrastructure access and services. According to EC (2010a):

*"The EU single market for electronic communications services, and in particular the development of very high-speed broadband services, is key to creating economic growth and achieving the goals of the Europe 2020 strategy. The fundamental role of telecommunications and broadband deployment in terms of EU investment, job creation and overall economic recovery was notably highlighted by the European Council in the conclusions of its March 2009 meeting."*

It can be thus concluded that very high-speed broadband services are widely accepted as strategically important not only because of their ability to accelerate the contribution of information and communications technology (ICT) to economic growth(Teppayayon and Bohlin, 2010), but also because network investments are potentially important targets of public investment during downturns as a way to increase demand and employment (Reynolds, 2009).

However, service providers are still reluctant to invest in NGA networks mainly due to the high investment cost and the ambiguity about the expected demand for the new fibre-based services. There are several theoretical economic approaches that aim to model the cost structure of investing in NGA networks, as well as, the impact of such investments on the future demand for the new fibre-based services. Most of these approaches assume that the investment cost is increasing and convex reflecting the fact that fibre deployment becomes marginally more expensive as it is extended to rural, less populated areas (Nitsche and Wiethaus, 2011; Foros, 2004). In addition, they also assume that the demand for the new fibre-based services is not affected by the relationship between the valuation that the consumers place to such services and their location (i.e. the population-affected type of the area they live in). Although these assumptions are useful for practical reasons; they fail to take into account the access networks' underlying morphology complexity and the consumers' socioeconomic characteristics, respectively.

This paper contributes to the emerging research on the investment in NGA networks by modifying the existing cost and demand structure assumptions in order to capture the access networks' underlying morphology complexity and the consumers' socioeconomic characteristics, respectively. Firstly, an empirical cost analysis is conducted for the 100 major municipal departments from urban to rural in Greece. Their street network data are analyzed as the basis of the NGA installation combining GIS technology and Graph Theory techniques and hence the main cost-drivers are derived. Using regression analysis a real-data-based cost function is obtained. Secondly, a novel model that takes into account socioeconomic characteristics affecting the impact of a certain level of NGA investment on consumers' willingness to pay is developed. The Pareto consumer distribution is used to reflect the greater (lower) positive impact of NGA investments on the willingness to pay of the consumers who live in more (less) populated areas.

The comparison of the existing models with the ones developed in this paper shows that: (i) the cost function used in the existing models always underestimates the investment cost of the higher populated areas and overestimates the investment cost of the lower populated areas; (ii) the demand for the new fibre-based services is higher under the proposed than the existing approach; and (iii) the level of NGA investment chosen by the investor is always much higher under the proposed than the existing approach.

The rest of the paper is as follows. In Section 2, the existing approach in terms of cost and demand functions is reviewed. Section 3 proposes a new approach to estimate the cost of deploying an NGA network based on real cost data from Greece and modifies the widely used demand model with network externalities in order to capture the fact that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) populated areas. Section 4 compares the results of the two approaches in terms of the optimal investment level for the investor and the subsequent levels of subscribers, investment costs, revenues and profits. The last section summarizes the main results of this article and proposes the directions for future work.

## 2. Existing approach

This section provides the existing cost and demand functions that are widely used in the literature of NGA investments in order to estimate the investment level that maximizes the investor's profits.

### 2.1 Existing cost models

Currently, most telecom operators are reluctant to significantly upgrade their telecommunication access network due to the high investment cost. Upgrade to NGA networks is generally perceived as the Fibre to the Curb (FTTC), Fibre to the Building (FTTB) and, of course, Fibre to the Home (FTTH) which is the ultimate and most future-proof access solution. To make any profound decisions on replacing some or all copper cable with optical fibre, a reasonably accurate cost model is needed, with enough detail on differences between deployments in different regions.

The related literature on telecommunications investments (Nitsche and Wiethaus, 2011; Foros, 2004) is based on very simplified assumptions regarding the cost structure. The investor in the abovementioned approaches determines the extent of NGA deployment, $R$. The investment level is considered continuous and a larger $R$ reflects a larger geographic coverage within a given market area (e.g. fibre to the outskirts rather than to the city centre, or to less populated cities). The NGA deployment is assumed to require investments of the following quadratic form:

$$C(R) = \frac{\varphi R^2}{2} \tag{1}$$

where $\varphi$ is an investment cost parameter. The convex form accounts for the assumption that deploying an NGA network becomes more expensive as the rollout is extended to rural, less populated areas indicated by a higher $R$.

In the case of investing in NGA networks in a nationwide level, $R$ can be seen as continuous in $[1, R_{max}]$ implying that $R = 1$ corresponds to the highest populated area and $R = R_{max}$ corresponds to the lowest populated area. Therefore, the whole areas within a country have been ranked in a decreasing order according to their population.

### 2.2 Existing demand models

There are many economic models that aim to estimate the demand for a good. Most of them base their analysis on the market structure of the industry in order to derive the demanded quantity. Examples of such models are those proposed by Cournot, Bertrand, Stackelberg, etc. These models are widely used in conventional markets in which there is a negative relationship between the demanded quantity for a good and its price. However, network markets, such as telecommunications, computers, electricity and railroads, present an innate characteristic that make them differ from conventional markets. In particular, the utility which a given user derives from the network good depends upon the number of other users who are in the same network. According to Katz and Shapiro (1985), this fact implies a positive consumption externality, which is widely known in the literature as network externality or network effect.[1] Economides (1996) points out that this fact seems quite counterintuitive since it goes against the downward-sloping market demand. Thus, he proposes that a positive consumption externality signifies the fact that the value of a unit of the good increases with the expected number of units to be sold. In this case, the demand slopes downward but shifts upward with increases in the number of units expected to be sold. Therefore, when expectations are fulfilled, the derived demand curve for a network good is concave.

[1] Some authors distinguish between direct and indirect network externalities. For a discussion on this issue see Economides (1996), Katz & Shapiro (1985), Page and Lopatka (1999) and Shy (2011).

Based on these observations, Shy (2011) models the demand for a network good. In particular, he assumes that potential subscribers can be indexed in a decreasing order according to the valuation (or utility) that they place on the network good. In particular, potential consumers are indexed by $x$, $x \in [0,1]$, where consumers that are indexed by low values of $x$ value the subscription highly, whereas consumers that are indexed by $x$ close to 1 place a low valuation on this service. Therefore, the variation in their willingness to pay for the network good forms a continuum of types of consumers. The (expected) utility of a potential subscriber indexed by $x$ is given by:

$$U_x = \begin{cases} (1 - \beta x)\alpha q^e - p, \text{ if the consumer subscribes} \\ 0, \text{ if the consumer does not subscribe} \end{cases} \tag{2}$$

where $p$ denotes the subscription fee, $q^e$ the expected total number of subscribers and $\beta > 0$ captures the degree of consumer heterogeneity with respect to consumers' benefit from this service. The parameter $\alpha > 0$ measures the intensity of network effects. Higher values of $\alpha$ indicate that consumers place higher value on the ability to communicate with the $q^e$ subscribers, whereas $\alpha = 0$ implies that there are no network effects.

A further assumption made by Shy (2011) is that the potential consumers are distributed uniformly in [0,1]. The uniform distribution of the consumers implies that in each type has been assigned a fixed number of potential consumers. Therefore the market demand is derived by multiplying the number of types whose utility is positive (i.e. buy the product or subscribe) with the fixed number of consumers of each type. For example, let there be $N$ potential subscribers of each type $x$, $x \in [0,1]$. Then, for a given subscription fee $p$, there is a consumer of type $0 \le x(p) \le 1$ who is indifferent between subscribing and not subscribing. Assuming perfect foresight, the total number of expected subscribers (or the demand for the network good) is $q_u^e = Nx(p)$.

However, in order to make investment costs and revenues comparable, we should transform the consumer type indexed by $x$, $x \in [0,1]$ into the range $[1, R_{max}]$. This implies that each consumer type $x$ corresponds to a given geographic area $R$. Lower values of $R$ imply that the consumer who lives in this area place a higher valuation to the network good. For this purpose, the normalization method with transformation $x = \dfrac{R - R_{min}}{R_{max} - R_{min}}$ is used. The notation $R$ stands for the original dissimilarity and $x$ for the normalized dissimilarity. Hence, the dissimilarity index $R$ (respectively, $x$) lies between $1$ and $R_{max}$ (respectively, 0 and 1). Applying the above normalization method yields the original dissimilarity as a function of the corresponding normalized dissimilarity:

$$R = x\left(R_{max} - 1\right) + 1 \text{, with } R \in \left[1, R_{max}\right] \tag{3}$$

Equation 3 shows that $R$ is continuous in $[1, R_{max}]$. In addition, $x = 0$ corresponds to $R = 1$ and $x = 1$ to $R_{max}$. This implies that the number of the *potential consumers* is $NR_{max}$, whereas the utility function of Shy (2001) becomes

$U_X = (R_{max} - \beta(x(R_{max} - 1) + 1))\alpha N(x(R_{max} - 1) + 1) - p$. Then, solving for $x$ yields the indifferent consumer:

$$x_{L,H}^{U} = \frac{\alpha N R_{max} - 2\alpha\beta N \pm \sqrt{\left(\alpha N R_{max}\right)^2 - 4\alpha\beta N p}}{2\alpha\beta N\left(R_{max} - 1\right)} \tag{4}$$

Therefore, the expected number of *potential subscribers* is given by:

$$q_{L,H}^{U} = N\left(\left(\frac{\alpha N R_{max} - 2\alpha\beta N \pm \sqrt{\left(\alpha N R_{max}\right)^2 - 4\alpha\beta N p}}{2\alpha\beta N\left(R_{max} - 1\right)}\right)(R_{max} - 1) + 1\right) \tag{5}$$

Since there exist two indifferent consumers between subscribing and not subscribing, there also exist two consumer equilibria. At every given price $p$, either a low or a high demand level would be realized according to consumers' expectations for the demand level. If all consumers correctly anticipate low demand, only those who value this service highly ($0 \leq x \leq x_{L}^{U}$) will subscribe. If all consumers anticipate high demand, the gain from a larger anticipated network will also induce consumers with lower valuations ($x_{L}^{U} \leq x \leq x_{H}^{U}$) to subscribe. Note that $q_{L}^{U}$ is an unstable equilibrium in the sense that a small increase in the number of subscribers would induce $q_{H}^{U}$ consumers to subscribe. Therefore, the demand (number of subscribers) for the network good is given by:

$$q_{H}^{U} = N\left(\left(\frac{\alpha N R_{max} - 2\alpha\beta N + \sqrt{\left(\alpha N R_{max}\right)^2 - 4\alpha\beta N p}}{2\alpha\beta N\left(R_{max} - 1\right)}\right)(R_{max} - 1) + 1\right) \tag{6}$$

It should be noted that, in existing markets, $R_{max}$ denotes the urban administrative divisions, i.e. municipal department (MD), of a country in which the consumers that place the lowest valuation on the new fibre-based services live. However, in the case of the NGA investments, this municipal department may not be covered by the investor. This implies that when a potential subscriber to the NGA services makes its decision to subscribe or not, s/he takes into account the expected number of subscribers to the NGA services rather than the whole population in a given country. Therefore, $R_{max}$ should be replaced by $R_{inv}$ which denotes the municipal department of a country that it is covered by the investor and in which the consumers that place the lowest valuation on the new fibre-based services live. In other words, $R_{inv}$ denotes the optimal investment level chosen by an investor in NGA networks. Therefore, the investor maximizes the following equation with respect to $R_{inv}$.

$$\Pi^{U} = P q_{H}^{U} - \frac{\varphi R_{inv}^{2}}{2} \Rightarrow$$

$$\Pi^{U} = PN\left(\left(\frac{\alpha NR_{inv} - 2\alpha\beta N + \sqrt{\left(\alpha NR_{inv}\right)^{2} - 4\alpha\beta Np}}{2\alpha\beta N}\right) + 1\right) - \frac{\varphi R_{inv}^{2}}{2} \tag{7}$$

## 3. The proposed approach

This section provides a more realistic approach concerning the development of NGA networks. In particular, the proposed cost and demand functions depart from the existing ones since the proposed model captures the access networks' underlying morphology complexity and the consumers' socioeconomic characteristics.

### 3.1 Proposed NGA investment cost

In this case, an empirical cost analysis conducted on a nationwide NGA network provides insights on the cost form, so that the validity and the accuracy of the conventional cost form may later be explored.

An approach is presented in this section for getting a clear estimate of expenses for an NGA rollout, particularly the most future-proof access solution of FTTH deployment, as the investment level increases from areas with large number of households (HH) to areas with small number of households. Calculations are made for the main cost-drivers using real street network data as the basis of a fixed NGA installation combining GIS technology and Graph Theory techniques.

For simplicity, the focus in this study is on the most important expenses that are the outside plant (OSP) capital expenditures (CAPEX). Earlier studies (Colle et al., 2008) indeed indicate that the major part of the total investment in a telecommunication access network is the capital investment made in the lower part of the network that connects a subscriber by a physical link to its corresponding Central Office (CO) via intermediate network components. Possible expenses on the active equipment or the regional/national/global backbone are not considered here.

*The architecture*

The considered FTTH architecture is presented in Figure 1. The model consists of a CO where all the optical line terminals are located, the feeder part of the network connecting the CO with flexibility points (FP), and the distribution part from FP to the end-users. The FP (or splitting point or cabinet) plays a concentration role, allowing the merging of customer cables. There are two popular technologies used with FTTH. The Point to Point (P2P) technology which uses all active components throughout the chain and Point to Multi-Point (P2M) / Passive Optical Network (PON) technology which uses passive optical splitters at the aggregation layer. For the purposes of this study the PON technology has been envisaged since it has been proven that P2P technology requires a rather costly infrastructure (Chatzi and Tomkos, 2011).Gigabit-capable Passive Optical Networks (GPON) are standardized by ITU-T under the family of recommendations G.984 (ITU-T, 2009) and are already in use in several countries. Here, the deployment of GPON FTTH is considered with a centralized 1:128 splitting ratio. This means that per group of 256 customers covered by each FP, only 2 fibres are needed for the FP-CO feeder part connection. Each CO is assumed to cover up to 100.000 households.

Also, a greenfield deployment is assumed and no existing infrastructure is taken into account. The installation closely follows one street with the cable located at the middle of the street and connects all households along the street. Of course, savings are possible if part of the network can be installed by means of aerial deployment, e.g. in areas with small number of households.

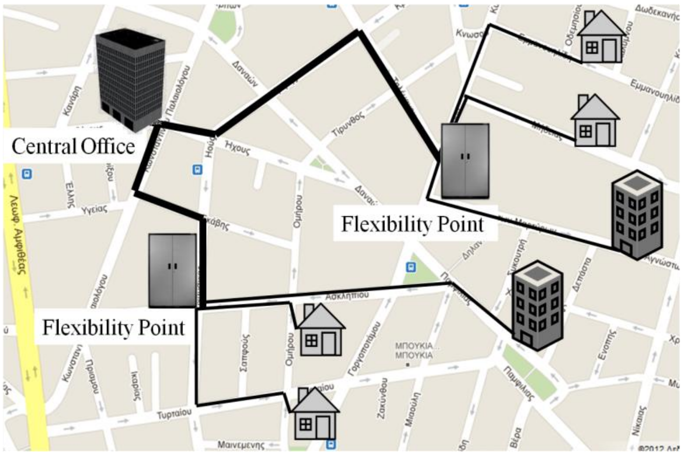


**Figure 1.** FTTH access network architecture

The regarded elements for the calculation of the total OSP CAPEX are the trenches, the ducts, the fibre cables, the splitters, the manholes, and the Y-branches. The individual components' costs were taken from (Chatzi and Tomkos, 2011). Any effects of changes in these prices to the total cost falls beyond the scope of this paper. The estimation of the volume of the material needed is described later on.

The use of geometric models is very often in techno-economics for analyzing the deployment area and estimating the OSP cost (Casier, 2009). Typically, these geometric abstractions of the installation region assume a regular grid-like structure where all lines have equal length and the same number of junctions. However, they cannot capture the complex details of the underlying urban street network in order to accurately estimate the key quantities for a cost evaluation of a fixed access network. In fixed access networks the cables run in trenches that use the road system as a natural guide to reach the customers. Access network nodes as well as connections strongly depend on the actual geography of the underlying urban street network and this has been proven to have a significant impact on the key quantities for estimating the deployment cost (Mitcsenkov et al., 2010; Maniadakis and Varoutas, 2012). For this reason a recently presented methodology (Maniadakis and Varoutas, 2012) that uses real GIS data is extended and applied for the cost analysis.

In this paper the 100 major MDs in Greece are selected in order to calculate and observe the form of the cumulative cost as the investment continues from the most populated down to the lowest populated MD in terms of households. The data are obtained from the collaborative project OpenStreetMap (OpenStreetMap, 2012) (GIS vector map) and the Hellenic Statistical Authority (Hellenic Statistical Authority, 2001) (number of HH, number of buildings, km$^2$ of area). The constructed dataset consists of 100 1-square-kilometer samples of street networks selected from the abovementioned municipal departments. Their data are imported in a GIS environment and are turned into spatial, weighted, undirected graphs using the Primal approach.

**Figure 2.** In the left it is the street network of the district sample of MD Nea Smirni, while to the right is the corresponding Primal graph split into square serving zones with buildings placed equidistant and FPs placed in the optimal locations

*Methodology and results*

Street networks are spatial, which is a special class of complex networks whose nodes are embedded in a two (or three) dimensional Euclidean space and whose edges do not define relations in an abstract space, but are real physical connections (Cardillo et al., 2006). Such a street network can be represented as a graph, which consists of a finite set of nodes and a finite set of edges. The graph nodes have precise position on the planar map, while the links follow the footprints of real streets and are associated a set of real positive numbers representing the street lengths.

A sample urban area is chosen and GIS data are collected without further GIS processing or analysis. The GIS data are then transformed to a spatial, weighted, undirected graph using the Primal approach (Porta et al., 2006) where intersections are turned into nodes and streets into edges, as shown in Figure 2. Depending on the number of buildings in the area, a new spatial network is made as an extension of the street network, with new nodes placed equidistance from neighbor nodes (inter building spacing - IBS) along the existing edges, so that the total number of nodes is equal to the number of buildings. In addition, depending on the number of HH in the area, a number of FPs is assigned at optimal locations applying the Closeness Centrality method. Each FP can serve a maximum number of households, e.g. 256, thus the total number of households is divided to this number to produce the required FPs. Then, the considered area needs to be split into serving zones, for example squares of equal size in order to serve approximately the same number of buildings/households. Each FP is associated with a serving zone such that the inscribed subnetwork that gathers all fibre lines between the FP and the subscribers displays a star structure that follows the underlying street network. The network can retain information in the edge weights, such as the trenching length, the size of the duct, the fibre length, etc. Then, the volume of the various network components may be computed with simple calculations on the graph weights, as described in (Maniadakis and Varoutas, 2012).

The cost is calculated for each 1-square-kilometer sample and then a cost/HH can be derived if the cost is divided with the number of HH in the sample, as shown in Figure 3 for the case of Greece. All costs are estimated for a project horizon of 20 years. The cost/HH per year is estimated to vary from 2,25€ to 265€.

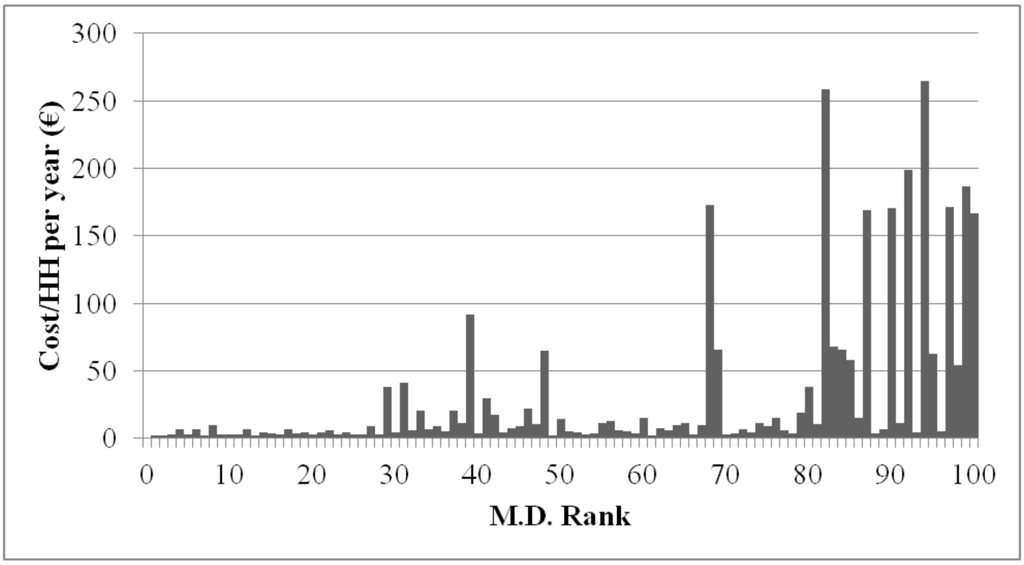


**Figure 3.** Cost per HH per year for the major MDs (sorted in number of HH) of Greece

The present study focuses on the 100 most populated MDs in terms of HH that vary from 301.566 HH to 5.953 HH and HH density that varies from 9.464 HH/km$^2$ to 24 HH/km$^2$. However, the vast majority of these MDs belongs to the high-dense HH MDs, as 67 out of 100 belong to the top-100 most densely populated MDs in HH. Thus, this means that either the investment grows from largest to lowest MD in terms of number of HH as described here, or from largest to lowest MD in terms of HH density, the cost results are similarly distributed. In total, the 100 MDs under investigation cover 2.089.992 HH or 57% of all HH in Greece.

Multiplying the above estimated cost per HH with the corresponding MD 's number of HH gives the cost per MD. Its cumulative distribution is depicted in Figure 4.

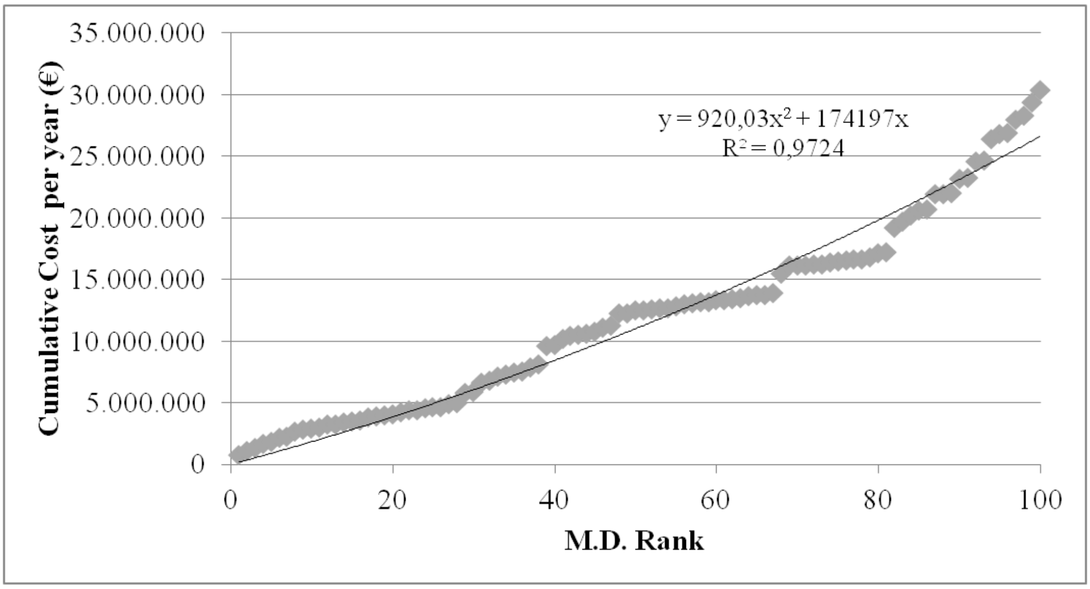


**Figure 4.** The cumulative cost per year for the major MDs (sorted in number of HH) of Greece

It is now convenient to derive the cost function that describes NGA investment as the investment level moves on greater level, covering less populated areas. Using regression analysis on the real cost data, the derived NGA investment cost function is given by:

$$C(R_{inv}) = 920{,}03 R_{inv}^{2} + 174197 R_{inv} \tag{8}$$

### 3.2 Proposed NGA demand

Although the uniformity assumption is convenient for deriving analytical results, it has been fiercely criticized in the literature. The reason is that uniform consumer distribution may not be highly satisfactory in representing actual consumer distributions in many markets (Ansari, Economides and Ghosh, 1994) and hence it is more realistic to assume non-uniform consumer distributions (Anderson, Goeree and Ramer, 1997).

Indeed, in many network markets, such as telecommunications, the valuation that the consumers place to the network good is significantly affected by their location (i.e. the population-affected type of the area they live in). The related literature studies the determinants of broadband availability, adoption and usage depending on location. For example, Flamm and Chaudhuri (2007) find a positive urban and suburban role in stimulating both dialup and broadband adoption. They attribute this result to social characteristics that make the internet and broadband use more attractive to urban and suburb dwellers than to rural folk. A more conclusive study that includes the main results of the related literature is Preston, Cawley and Metykova (2007) which analyze the status of broadband in rural areas in the EU. They look at availability, adoption and use of broadband, taking a policy perspective drawing from the results of the BEACON research, which provides an analysis of the broadband situation in each of the 25 EU countries. Their main findings are: a geographic broadband divide; lower investment in infrastructure in rural areas; where broadband is available, lack of competition in infrastructure and services; the fact that the rural broadband divides go along with other traditional divides; the fact that rural areas suffer from declining and aging population; the fact that the rural dwellers tend to be slower adopters; the fact that the rural areas have less technical support; the circumstance that social factors that facilitate broadband use (such as education, profession, economic status and cultural practice) can be less favourable in rural communities. The main take-away of the above studies is that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) populated areas.

This conclusion signifies the fact that uniform consumer distribution fails in representing the actual demand in telecommunications markets in which the consumers' valuation for the good varies according to the population of the location (area) they live in. Thus, the aim of this section is to estimate the demand for the new fibre-based services when the relationship between location and valuation for the good is taken into account. This implies that the distribution of the consumers to their different types is not uniform but follows a certain non-uniform distribution that captures the fact that consumers who place a higher (lower) valuation to the network good tend to live in areas with higher (lower) population.

A particular type of non-uniform distribution in literature that can describe the population allocation in urban divisions is the power law or Pareto distribution (Soo, 2005). This distribution, when plotted on double logarithmic axes, shows a remarkable linear pattern where the slope of the line is usually close to -1, corresponding to the well-known Zipf's law distribution (Zipf, 1949). This type of non-uniform distribution is quite appropriate to chose since it states that a size is inversely proportional to its rank in a sorted order. For example, in the case of populations, the population size of each city in a country appears to be inversely proportional to the city rank. Therefore, the variation in the population of each area forms a continuum of areas. This fact is in full accordance with the model proposed by Shy (2011) and hence they can be easily compared.

In Figure 5 there are presented the most populated municipal departments of Greece in terms of households. Specifically, there are included MDs until 100 HH (3679 MDs in total). Their HH-Rank distribution fits a power law ($R^2$>0,99) with a power law exponent near -1, indicating a Zipf distribution.

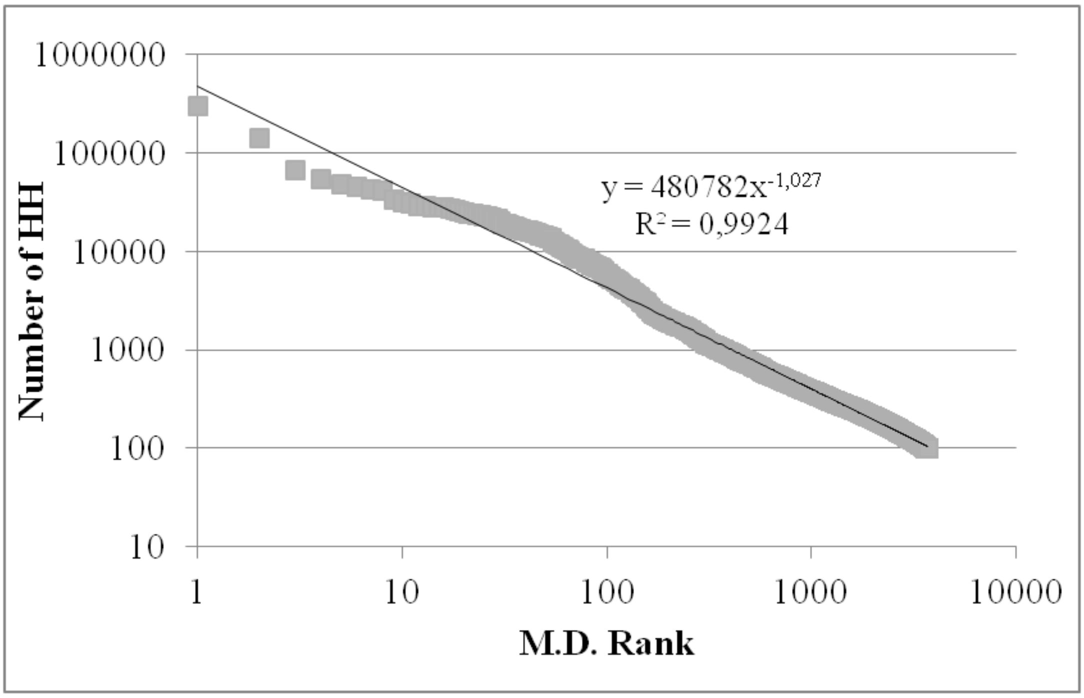


**Figure 5.** HH distribution is a Zipf distribution; the case of Greece (2001)

As mentioned by Kyriakidou, Michalakelis and Varoutas (2011), Zipf's law can be described by the following equation:

$$Rank\ x\ Population = Constant \Leftrightarrow Population = \frac{Constant}{Rank} \Leftrightarrow pop(R) = \frac{C}{R} \qquad (9)$$

Let rank the MDs according to their HH number in a decreasing order. Then, $R_{min} = 1$ denotes the area with the highest population and $R = R_{max}$ denotes the area with the lowest population. Figure 6 plots the non-uniform distribution of consumers according to their willingness to pay.

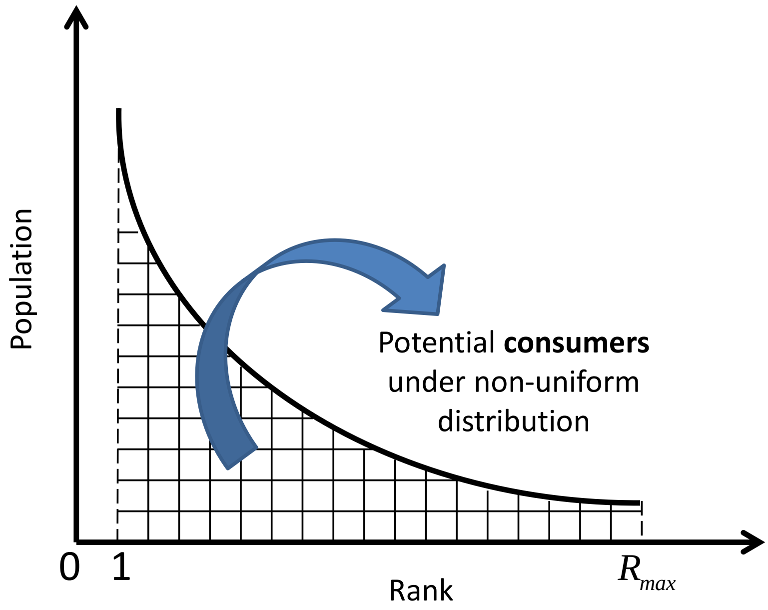


**Figure 6.** Non-uniform distribution of consumers according to their willingness to pay

Figure 6 reflects the fact that consumers with high willingness to pay live in areas with high population. However, the distribution of consumers according to their willingness to pay (or equivalently the rank of the areas they live in) is not uniform, but follows the Zipf's law. Therefore, the maximum number of *potential consumers* is represented by the shaded region of the above figure, which is given by:

$$q_{n-u}^{max} = \int_{1}^{R_{max}} pop(R)dR = \int_{1}^{R_{max}} \frac{C}{R}dR = C\left[ln|R|\right]_{1}^{R_{max}} = Cln\left(R_{max}\right) \quad (10)$$

Similar to Shy (2011), only those types of consumers whose valuation for the network good is positive buy the good or subscribe. Therefore, for a given subscription fee $p$, there is a consumer of type $0 \le x(p) \le 1$ who is indifferent between subscribing and not subscribing. This indifferent consumer is affected by the expected total number of subscribers which is given by:

$$q_{n-u}^{e} = \int_{1}^{x(R_{max}-1)+1} pop(R)dR = \int_{1}^{x(R_{max}-1)+1} \frac{C}{R}dR = C\left[ln|R|\right]_{1}^{x(R_{max}-1)+1} \Rightarrow$$

$$q_{n-u}^{e} = Cln\left(x(R_{max}-1)+1\right) \quad (11)$$

Substituting Eq. (11) into Eq. (2) and using Eq. (3) gives the (expected) utility of a *potential subscriber* indexed by $x \in [0,1]$ when the distribution of consumers according to their willingness to pay follows the Zipf's law:

$$V_X = \begin{cases} (R_{max} - \beta(x(R_{max} - 1) + 1))\alpha Cln(x(R_{max} - 1) + 1) - p, \text{ if the consumer subscribes} \\ 0, \text{ if the consumer does not subscribe} \end{cases} \quad (12)$$

Solving Eq. (12) with respect to $x$ yields the indifferent consumer:

$$x^V_{L,H} = \frac{\alpha C R_{max} - \alpha\beta C \pm \sqrt{(.)}}{2\alpha\beta C\left(R_{max} - 1\right)} \tag{13}$$

where

$$\sqrt{(.)} = \sqrt{(\alpha\beta C)^2 + \left(\alpha C R_{max}\right)^2 - 2\alpha^2\beta C^2 R_{max} - 4p\alpha\beta C} \tag{14}$$

Then, by substituting Eq. (13) into Eq. (11), the expected number of *potential subscribers* is derived:

$$q^V_{L,H} = C ln\left(\frac{\alpha C R_{max} - \alpha\beta C \pm \sqrt{(.)}}{2\alpha\beta C} + 1\right) \tag{15}$$

Once again, it is proven that $q^V_L$ is an unstable equilibrium in the sense that a small increase in the number of subscribers would induce $q^V_H$ consumers to subscribe. Therefore, the demand (number of subscribers) for the network good is given by:

$$q^V_H = C ln\left(\frac{\alpha C R_{max} - \alpha\beta C + \sqrt{(.)}}{2\alpha\beta C} + 1\right) \tag{16}$$

which is represented by the shaded region in Figure 7.

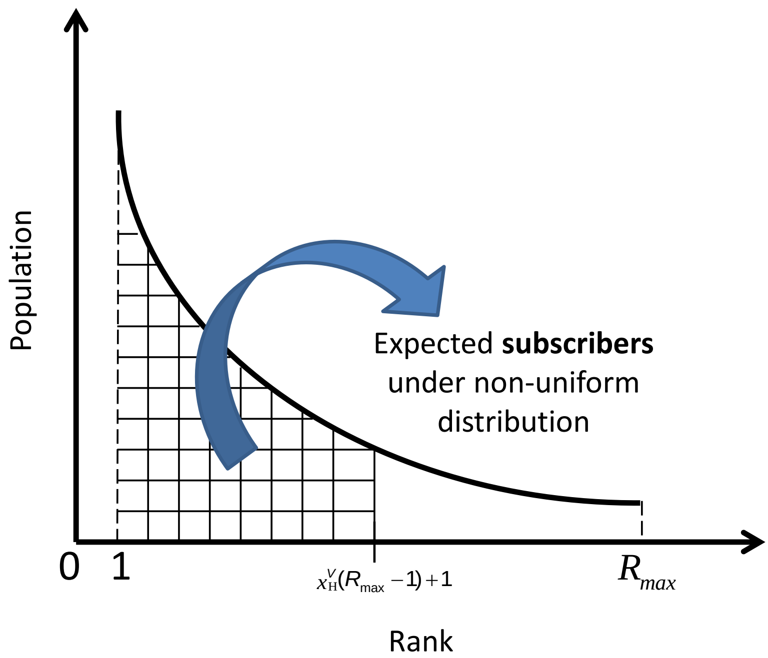


**Figure 7.** Demand with non-uniform consumer distribution

As in the case of the existing approach, $R_{max}$ should be replaced by $R_{inv}$ in order to capture the fact that a potential subscriber to the NGA services makes its decision to subscribe or not based on the expected number of subscribers to the

NGA services rather than the whole population in a given country. Therefore, the investor maximizes the following equation with respect to $R_{inv}$.

$$\Pi^V = Pq_H^V - 920{,}03R_{inv}^2 + 174197R_{inv} \Rightarrow$$

$$\Pi^V = PCln\left(\frac{\alpha CR_{inv} - \alpha\beta C + \sqrt{(.)}}{2\alpha\beta C} + 1\right) - (920{,}03R_{inv}^2 + 174197R_{inv}) \quad (17)$$

where

$$\sqrt{(.)} = \sqrt{(\alpha\beta C)^2 + (\alpha CR_{inv})^2 - 2\alpha^2\beta C^2 R_{inv} - 4p\alpha\beta C} \quad (18)$$

## 4. Comparison of the two approaches

This section compares the outcomes of the two approaches in terms of the optimal investment level ($R_{inv}^i$) and the subsequent levels of subscribers ($q_H^i$), investment costs ($C_{inv}^i$), revenues ($R^i$) and profits ($\Pi^i$), where the superscript $i = U,V$ stand for the existing and the proposed approach, respectively. The main part of the analysis that follows is conducted via numerical simulations due to the complexity of closed-form solutions for the endogenous variable $R_{inv}$ in Eqs. (7) and (17). The optimal investment levels for the investor under both approaches are derived for 9 different scenarios concerning different values of the independent parameters $\beta$ and $\varphi$. These parameters are chosen because the sensitivity analysis conducted showed that $\beta$ and $\varphi$ have the more powerful impact on total profits. In order to define the other independent parameters actual data from Greece are used. In particular, $C = 400000$ denotes the most populated municipal department in Greece (see Figure 5) and $P = 480$ denotes the annual average price per household. In addition, the level of $\alpha$ is chosen arbitrarily to 1 since sensitivity analysis shows that $\alpha$ does not significantly affect the final results.

A very significant observation is that the total number of HH is the same either if they are uniformly or non-uniformly distributed to the different municipal departments. In the former case the total number of HH is $NR_{max}$, whereas in the latter case the total number of HH is $Cln(R_{max})$. Equating the two populations and solving with respect to $N$ gives the fixed number of HH assigned by Shy (2001) to each municipal department:

$$N = C\frac{ln(R_{max})}{R_{max}} \quad (19)$$

In the case of Greece, $R_{max} = 6122$ since there are 6122 municipal departments. Therefore, Shy (2001) assigns 570 HH to every of 6122 municipal departments. The final results can be summarized in Tables 1 and 2.

**Table 1**

| | | $R_{inv}^{U}$ | $R_{inv}^{V}$ | $x_H^U$ | $x_H^V$ | $q_H^U$ | $q_H^V$ |
|---|---|---|---|---|---|---|---|
| $\beta = 1,00$ | $\varphi = 5.000$ | 54,70 | 279,14 | 0,99 | 0,99 | 31.160 | 2.252.684 |
| $\beta = 1,00$ | $\varphi = 10.000$ | 27,37 | 279,14 | 0,99 | 0,99 | 15.580 | 2.252.684 |
| $\beta = 1,00$ | $\varphi = 15.000$ | 18,27 | 279,14 | 0,99 | 0,99 | 10.387 | 2.252.684 |
| $\beta = 1,45$ | $\varphi = 5.000$ | 37,75 | 279,14 | 0,68 | 0,68 | 14.821 | 2.252.684 |
| $\beta = 1,45$ | $\varphi = 10.000$ | 18,92 | 279,14 | 0,67 | 0,68 | 7.140 | 2.252.684 |
| $\beta = 1,45$ | $\varphi = 15.000$ | 12,67 | 279,14 | 0,66 | 0,68 | 4.940 | 2.252.684 |
| $\beta = 1,90$ | $\varphi = 5.000$ | 28,84 | 279,14 | 0,51 | 0,52 | 8.632 | 2.252.684 |
| $\beta = 1,90$ | $\varphi = 10.000$ | 14,50 | 279,14 | 0,49 | 0,52 | 4.316 | 2.252.684 |
| $\beta = 1,90$ | $\varphi = 15.000$ | 9,76 | 279,14 | 0,46 | 0,52 | 2.878 | 2.252.684 |

**Table 2**

| | | $C_{inv}^{U}$ | $C_{inv}^{V}$ | $R^U$ | $R^V$ | $\Pi^U$ | $\Pi^V$ |
|---|---|---|---|---|---|---|---|
| $\beta = 1,00$ | $\varphi = 5.000$ | 7.482.694 | 120.312.585 | 14.956.961 | 1.081.288.267 | 7.474.267 | 960.975.682 |
| $\beta = 1,00$ | $\varphi = 10.000$ | 3.747.679 | 120.312.585 | 7.478.489 | 1.081.288.267 | 3.730.810 | 960.975.682 |
| $\beta = 1,00$ | $\varphi = 15.000$ | 2.505.512 | 120.312.585 | 4.985.685 | 1.081.288.267 | 2.480.173 | 960.975.682 |
| $\beta = 1,45$ | $\varphi = 5.000$ | 3.563.062 | 120.312.585 | 7.113.898 | 1.009.948.067 | 3.550.836 | 889.635.482 |
| $\beta = 1,45$ | $\varphi = 10.000$ | 1.790.753 | 120.312.585 | 3.556.988 | 1.009.948.067 | 1.766.235 | 889.635.482 |
| $\beta = 1,45$ | $\varphi = 15.000$ | 1.204.186 | 120.312.585 | 2.371.439 | 1.009.948.067 | 1.167.253 | 889.635.482 |
| $\beta = 1,90$ | $\varphi = 5.000$ | 2.079.628 | 120.312.585 | 4.143.218 | 958.052.323 | 2.063.590 | 837.739.738 |
| $\beta = 1,90$ | $\varphi = 10.000$ | 1.051.994 | 120.312.585 | 2.071.725 | 958.052.323 | 1.019.731 | 837.739.738 |
| $\beta = 1,90$ | $\varphi = 15.000$ | 715.171 | 120.312.585 | 1.381.484 | 958.052.323 | 666.313 | 837.739.738 |

The values of $\beta$ are chosen in order to ensure that $0 \leq x(p) \leq 1$, whereas the values of $\varphi$ represent three different scenarios concerning the relationship between the investment cost function given by Eq. (1) and the real-cost-data-based investment cost function given by Eq. (8). Figure 8 shows that regardless of the particular value of $\varphi$, Eq. (1) always underestimates the investment cost of the higher populated MDs and overestimates the investment cost of the lower populated MDs. In particular, the lower the value of $\varphi$, the more underestimated (overestimated) the investment cost of the higher (lower) populated MD becomes. This implies that the lower the value of $\varphi$, the lower populated is the MD that the cost functions of Eqs. 1 and 8 result to the same deployment cost.

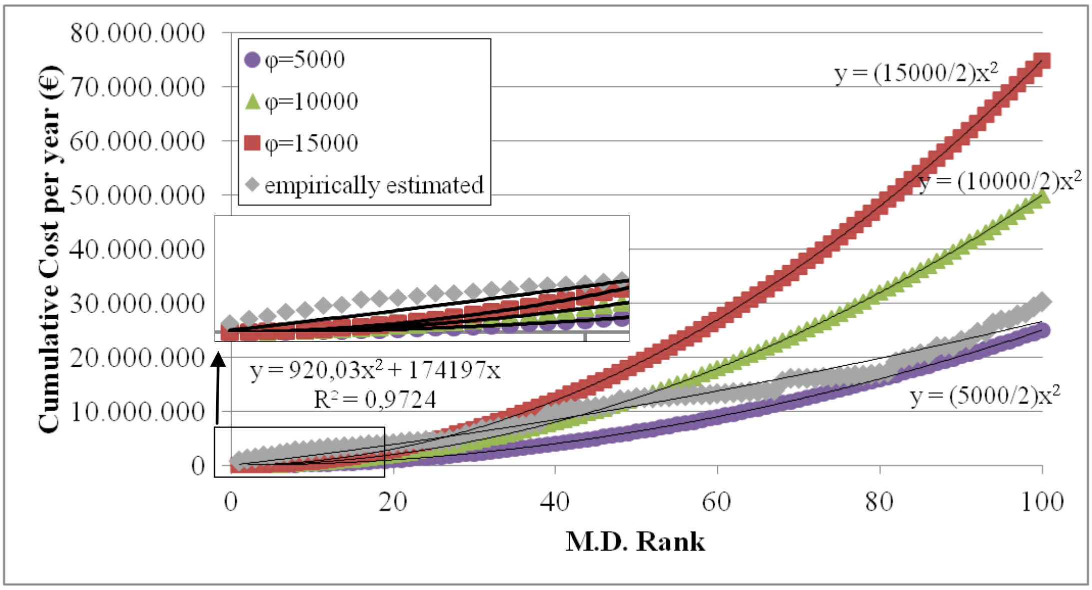


**Figure 8.** Cumulative investment cost per year

A number of observations derived by the analysis of Table 1 and 2 are instructive. An increase in $\varphi$ and/or $\beta$ leads $R_{inv}^{U}$ to decrease, whereas $R_{inv}^{V}$ is not affected by a change in $\varphi$ and/or $\beta$. The comparison between $R_{inv}^{U}$ and $R_{inv}^{V}$ shows that $R_{inv}^{V}$ is always much greater than $R_{inv}^{U}$. Since the indifferent subscriber is almost the same in both approaches, it is reasonable that the number of subscribers is higher under the proposed than the existing approach. This, in turn, results in higher revenues under the proposed than the existing approach since it is assumed that the price of the service is the same under both approaches. Concerning the deployment cost, it is shown that an increase in $\varphi$ and/or $\beta$ leads $C_{inv}^{U}$ to decrease, whereas $C_{inv}^{V}$ is not affected by a change in $\varphi$ and/or $\beta$. The comparison between $C_{inv}^{U}$ and $C_{inv}^{V}$ shows that $C_{inv}^{V}$ is always much greater than $C_{inv}^{U}$.

Another very significant finding is that an increase in $\beta$ negatively affects the investor's profits under both approaches. However, the investor's profits under the proposed approach are much greater than the investor's profits under the existing approach. The main reason for this result is that the uniformity assumption underestimates the number of households in the most populated areas where the cost per household is lower. This partially interprets the investor's decision to limit its investment level under the existing approach. This, in turn, decreases the expected number of subscribers, which also decreases the actual number of subscribers.

Therefore, the departure from the uniformity assumption allows capturing the fact that subscribers who place a higher valuation to broadband subscription tend to live in higher populated areas where the cost per household is lower. It is thus obvious why the proposed approach leads to much higher investment level than the existing approach.

## 5. Conclusions

The aim of this paper was twofold; firstly to investigate whether the traditional quadratic convex cost form is suitable for being used in NGA investments; and secondly to propose a more realistic demand model. Thus, (i) an empirical cost analysis was conducted for a real case of NGA deployment and a real-data-based cost function was obtained; and (ii) the Pareto consumer distribution was used to reflect the greater (lower) positive impact of NGA investments on the willingness to pay of the consumers who live in more (less) populated areas.

In the case of the investment cost, the existing assumption of the quadratic convex cost form was found inaccurate when compared with the cost estimation conducted for the 100 major municipal departments in terms of HH in Greece. The methodology used for the cost estimation took into account the underlying street morphology complexity that the classic approaches ignore due to the use of the simple geometric models. In particular, the cost function used in the existing models always underestimates the investment cost of the higher populated areas and overestimates the investment cost of the lower populated areas.

Concerning the demand for the new fibre-based services, it was found that the existing demand models with network externalities always underestimate such demand since they assume uniform consumer distribution. The reason is that the uniformity assumption underestimates the number of households in the most populated areas where the cost per household is lower. Therefore, the optimal investment level from an investor's perspective is always much higher under the proposed approach than the traditional one.

Although this article provided some very useful results, there are many directions to be extended in order to overcome its limitations. First, the derived cost structure is based on actual cost data from Greece and hence its robustness should be investigated by using cost data from other countries. Second, this article neglects the impact of competition on the retail price, as well as, regulatory issues concerning the access price that an access seeker should pay to the investor in order to have access to the new fibre-based infrastructure.

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**M. Tselekounis and D. Varoutas, "Modeling the regulatory uncertainty of NGA investments under cost-based access rules," in *7th International Conference on Competition and Regulation (CRESSE), July 2012, Chania, Greece*.**

# Modeling the regulatory uncertainty of NGA investments under cost-based access rules

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ABSTRACT

We study the impact of the regulatory uncertainty on the incumbents' incentives to invest in NGA networks under cost-based access rules. It is found that the incumbents underinvest unless they are compensated for the regulatory risk they incur in practice. The optimal risk premium that reflects the regulatory uncertainty is derived, as well as, its impact on the levels of NGA investment and competition. The main conclusion of this paper is that when the slope of the marginal cost function of the investment is significantly but not extremely steep, a cost-based access price that incorporates a markup for the demand uncertainty and a premium for the regulatory uncertainty leads to higher levels of both NGA investment and consumer surplus. Therefore, we show that, under plausible assumptions, the current regulatory practice in the European NGA market described by the EC Recommendation on regulated access to NGA can tackle the regulatory trade-off between encouraging efficient NGA investments and promoting effective competition.

**Keywords:** access regulation, competition level, investment incentives, regulatory uncertainty, telecommunications

**JEL classification:** L43, L51, L96

## 1. Introduction

The migration from the traditional copper networks to the Next Generation Access (NGA) networks[1] has induced a growing interest in access regulation and investment incentives. Given that the prospective investors in NGA networks are for large part the former incumbent operators (OPTA, 2010), the goal of regulators is to promote effective competition and encourage efficient and timely investments in NGA networks from the incumbents.

However, the regulators' two-fold goal is related to the common trade-off between static and dynamic efficiencies. On the one hand, mandated access at cost-based prices reduces the use of monopoly power over the access infrastructure by preventing the incumbent from foreclosing the entrant from the downstream (retail) market. Access regulation thus leads to sustainable service-based competition within one network and, hence, improves static efficiency (Valletti, 2003; Bouckaert, van Dijk and Verboven, 2010). On the other hand, mandating the access at cost-based prices discourages both incumbents and potential entrants to invest in access infrastructures (Jorde, Sidak and Teece, 2000). According to Cave and Prosperetti (2001), the reason for this negative relationship between access regulation and incumbents' incentives to invest is that the incumbents anticipate that they will be required to offer access to their rivals at cost-based prices. Therefore, potential entrants, who can free-ride on the incumbent's network, will wait for the incumbent to invest in access infrastructure and then seek access (Valletti, 2003). The conclusion is that cost-based access regulation, which is limited to promote service-based competition, leads to losses in dynamic efficiency (Bouckaert, van Dijk and Verboven, 2010).

Cambini and Jiang (2009) provide an excellent review of the theoretical and empirical literature on the relationship between broadband investment and regulation. They conclude that although cost-based access prices lead to the aforementioned regulatory trade-off, there is still an ambiguity about access regulation and its linkage with overall investment incentives that should be further investigated. In this direction, Siciliani (2010) proposes a mechanism for preventing regulatory failures stemming from the demand-side uncertainty. However, according to OPTA (2008), not only the uncertainty about future demand for new fibre-based services deters the incumbent from investing in NGA networks, but also the regulatory uncertainty related to the regulator's limited ability to make *ex ante* credible commitments.[2] Contrary to Siciliani (2010), we focus on the impact of regulatory uncertainty on the NGA investment level, which is one of the main open telecommunications policy issues worldwide. Since the regulators' goal is not only to encourage investments in NGA networks, but also to promote effective competition, the impact of regulatory uncertainty on the subsequent level of consumer surplus, which is used as a measure of the intensity of the competition in the retail market, will also be discussed.

[1] According to EU Commission (2010) Next Generation Access (NGA) networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network.

[2] For an extensive review of all the factors influencing the riskiness of an NGA investment project, see ERG (2009), pp. 17-18, WIK (2009), pp.1-7 and EU Commission (2010), page 18.

## 2. Regulatory uncertainty: A literature review

The related literature provides two different approaches for studying the relationship between access regulation and the incumbent's incentives to invest in network upgrade (e.g. in NGA networks). The first assumes that the incumbents decide their optimal investment level prior to the regulation of the access price. This implies that the regulator cannot make *ex ante* credible commitments on its future interventions and hence the incumbents invest under regulatory uncertainty. Based on this assumption, Foros (2004) and Katakorpi (2006) study the investment of an incumbent in quality anticipating that the regulator will set the access price to the marginal cost of providing the access since this policy maximizes social welfare. They conclude that cost-based access price provides the incumbent with disincentives to invest unless it is much more efficient than its rivals in the downstream market. In addition, Lewin, Williamson and Cave (2009) argue that a lack of clarity over how incumbents will be regulated, particularly in terms of price when they have significant market power (SMP) in NGA supply, is deterring them from investing in NGA networks.

The second approach assumes that the regulation of the access price takes place prior to the incumbents' investment decision. According to Nitsche and Wiethaus (2010) and Valletti and Cambini (2005), this implies that there is no regulatory commitment problem. However, in fact, the regulator's *ex ante* commitment bears the risk of erroneous intervention. A regulator's commitment for a long regulatory period may result in either incumbents' inability of recouping their investment costs or excessive prices that harm competition. Therefore, it is socially not optimal for the regulator to make ex ante commitments for an unreasonably long regulatory period (WIK, 2009). It is obvious that short-run regulatory policies increase the regulatory uncertainty that the incumbents incur when investing in NGA networks. Therefore, in providing greater regulatory certainty the regulator has to make another trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare (OPTA, 2010).

As a result, even if the regulator sets the access price prior to the investment stage, the regulatory commitment problem still exists. This implies that both approaches make the incumbents reluctant to invest in NGA networks because of the regulator's limited ability to commit to its future intervention. Therefore, potential investors are reluctant to invest in NGA networks unless they are reimbursed for the risk they incur when investing in such networks. Based on this conclusion, the European Commission (EC) issued a Recommendation on regulated access to NGA (EU Commission, 2010) in order to provide the National Regulatory Authorities (NRAs) with guidelines for encouraging efficient and timely investments in NGA networks from the incumbents and promoting effective competition.

In particular, the EU Commission (2010) endorses the opinion of OPTA (2010) that *"from the perspective of an investor, uncertainty is only reduced when the regulators discloses intended regulatory intervention before the investment is made"*. Thus, the regulation of the access price is proposed to take place prior to the incumbents' investment decision. In addition the EC admits that regulatory certainty is a key factor to promote efficient investments by all operators. For this reason, the EC recommends calculating the access in a cost-based form that incorporates a risk premium. This premium should reflect any additional and quantifiable investment risk incurred by the investor.[3]

The aim of this paper is to assess the risk premium that reflects the regulatory uncertainty according to the rules proposed by the EU Commission (2010). This implies that the access price should be cost-based incorporating a risk premium for the demand uncertainty and a risk premium that reflects the regulatory uncertainty. Sarmento and Brandao (2007) assume an access price equal to the marginal cost of providing the access plus the average cost of the investment. Such an access pricing formula is cost-based and we can assume that the access markup aims at reimbursing the investor for the demand uncertainty of NGA investments. We also use the access pricing formula proposed by Sarmento and Brandao (2007) but we allow for a risk premium that reflects the regulatory uncertainty.

The calculation of the regulatory risk premium is based on the comparison of the results obtained when the incumbent invests in network upgrade before and after the regulation of the access price. The first case has been already studied by Sarmento and Brandao (2007) who compare the impact of deregulation, cost-based regulation and retail-minus regulation on foreclosure, investment level and consumer surplus when the incumbent decides its optimal investment level prior to the regulation of the access price. On the contrary, we reverse the timing of the game assumed by Sarmento and Brandao (2007) in order to compare the results of the two approaches and to derive the risk premium that reflects the regulatory uncertainty of the investments in NGA networks under cost-based access rules. For the rest of the paper, we will call the approach of Sarmento and Brandao as “the incumbent’s approach” and our approach as “the regulator’s approach” since in the former case the incumbent acts as a leader in the market, whereas in the latter case the regulator acts as a leader and the incumbent as a follower.

It should be noted that, to best of authors’ knowledge, this is the first formal attempt to calculate the risk premium for the regulatory risks in a theoretical way.[4] The rest of the paper is organized as follows. Section 3 gives an outline of the basic assumptions and definitions of the model. Section 4 briefly recalls the results of Sarmento and Brandao (2007) under cost-based regulation. Section 5 studies the impact of cost-based regulation on competition and investments under “the regulator’s approach”, compares the results of the two approaches, calculates the risk premium and justifies regulatory implications. The last section summarizes the key findings of this paper.

## 3. The model

The aim of this paper is twofold. First, it aims to test the results of “the incumbent’s approach” under the assumption that the access price is set prior to the incumbent’s investment decision. Second, based on the comparison of the obtained results, it aims to calculate the risk premium that reflects the regulatory uncertainty of an investment in NGA networks. Since the obtained results should be comparable with those of Sarmento and Brandao (2007), the model used in

[3] See EU Commission (2010), Annex I.

[4] OPTA (2010) has calculated a fixed premium of 3,5% for regulatory risks. However, we consider that this is the result of a techno-economic analysis since OPTA (2008) use such an analysis for deriving its optimal policy for regulating NGA investments.

this paper is identical to the model used by Sarmento and Brandao (2007) except of the timing of the game. In particular:

- The retail (downstream) market is characterized as an unregulated duopoly market in which the incumbent (the subsidiary firm of the upstream monopolist) acts as a Stackelberg leader and the entrant (the independent firm) act as a Stackelberg follower.
- The quality of the input sold by the monopolist is the same whether it is sold to the incumbent or to the entrant. It is also assumed that the production of one unit of the retail service requires one unit of the upstream input (fixed coefficients technology).
- The inverse demand function is given by $p = 1 + \beta I - (q_1 + q_2)$, where $p$ is the retail market price, $q_1$ and $q_2$ are the quantities supplied by the incumbent and the entrant respectively, $I$ represents the level of the NGA investment undertaken by the incumbent, and $\beta$ represents the impact of a marginal change in the investment level on the retail price (ceteris paribus). It is further assumed that $\beta > 0$, which implies that an increase in the NGA investment level leads to an outward parallel shift in the demand that benefits both retailers.
- The NGA deployment is continuous where a larger $I$ reflects a fibre deployment closer to the consumers' premises. The incumbent faces a quadratic NGA investment cost with respect to $I$, given by $c(I) = \varphi I^2 / 2$, with $\varphi > 0$. The convex form reflects the fact that fibre deployment becomes marginally more expensive as (i) it is being laid down towards consumers' premises, and/or (ii) it is extended to rural, less densely populated areas. It is further assumed that the NGA investment level does not have any impact on the (fixed) marginal cost of providing the access denoted by $c$, ($c < 1$). The access price that the entrant should pay to the incumbent in order to have access to the incumbent's network is represented by $w$, assuming $w \geq c$. The cost of all other inputs is equal for both retailers and normalized to zero. Therefore, the profits functions of the incumbent (firm 1) and the entrant (firm 2) are given, respectively, by

$$\pi_1 = (p - c)q_1 + (w - c)q_2 - \varphi I^2 / 2 \tag{1}$$

$$\pi_2 = (p - w)q_2 \tag{2}$$

- The timing of the game presented by Sarmento and Brandao (2007) is as follows:
  - First, the incumbent decides the investment level $I$.
  - Secondly, the regulator chooses the access price $w$.
  - Finally, the retail price and outputs of the firms are defined by Stackelberg competition between downstream firms.

  This paper provides an alternative approach by reversing the first two stages. Therefore, the timing of the game presented by this paper is as follows:

  - First, the regulator chooses the access price $w$.
  - Secondly, the incumbent decides the investment level $I$.

- Finally, the retail price and outputs of the firms are defined by Stackelberg competition between downstream firms.

The backward induction technique is used to find the equilibrium of the whole game. Therefore, the analysis begins with the computation of the retail price and the outputs of the firms. Then, using these results, the incumbent's optimal investment level is obtained. Finally, based on the previous information, the optimal access price is derived.

## 4. The incumbent's approach

This section briefly recalls the results of Sarmento and Brandao (2007). In particular, each firm's output, total output and investment level under cost-based regulation are:

$$q_1^I = \frac{\varphi(1-c)(4+\varphi-\beta)}{2(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} \tag{3}$$

$$q_2^I = \frac{\varphi(1-c)(2-\beta)}{2(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} \tag{4}$$

$$q^I = \frac{\varphi(1-c)(6+\varphi-2\beta)}{2(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} \tag{5}$$

$$I^I = \frac{(1-c)(\beta+\varphi)}{4\varphi-\beta^2+\varphi^2-2\beta\varphi} \tag{6}$$

Note that total output $q^i$, ($i=I,R$ with *I* and *R* denote the results obtained by the incumbent's and the regulator's approach, respectively), is a measure of competition since consumer surplus (*CS*) is given by $CS=(q^2)/2$. This implies that since the demand function is linear, a larger $q^i$ leads to a larger CS.

## 5. The regulator's approach

Contrary to "the incumbent's approach", this section assumes that first the regulator sets the access price and then the incumbent chooses its optimal NGA investment level. In particular, this section initially provides the results obtained by an access pricing scheme that does not incorporate any risk premium (i.e. there is no regulatory commitment problem). Then, these results are compared with those obtained by "the incumbent's approach" in order to derive the risk premium that compensates the incumbent for the regulatory risk it incurs. Last, it provides the specific conditions under which the incorporation of a risk premium into the access price is beneficial for the consumers. If these conditions hold, the incorporation of such a risk premium into the access price is the optimal regulatory policy. If, on the contrary, these conditions do not hold, the regulatory policy should tackle the trade-off between encouraging NGA investments and promoting competition.

*5.1. Access pricing without risk premium*

Considering Stackelberg competition, the retail price and the output of the firms are the following:

$$q_1^R = (1+\beta I - c)/2 \tag{7}$$

$$q_2^R = (1+\beta I - 2w + c)/4 \tag{8}$$

$$P = (1+\beta I + 2w + c)/4 \tag{9}$$

Substituting Eqs. (7), (8) and (9) in (1) and taking the first order condition of Eq. (1) with respect to $I$, gives the NGA investment level that maximizes the incumbent's profits:

$$I^R = \beta(1+2w-3c)/(4\varphi - \beta^2) \tag{10}$$

Since $w \geq c$ and $c < 1$, the numerator of Eq. (10) is positive. Therefore, in order to guarantee that $I > 0$, the following assumption is made:

**Assumption 1.** Let $4\varphi - \beta^2 > 0$.

This assumption guarantees that $\varphi$ is relative high, which means that the slope of the marginal cost function of the investment is significantly steep. It should be noted that this approach requires a lower $\varphi$ than "the incumbent's approach" in order to guarantee that the NGA investment level is positive. The implication is that since $\varphi$ and $\beta$ are both exogenous factors, "the regulator's approach" leads to a positive investment level for more combinations of $\varphi$ and $\beta$ than "the incumbent's approach". However, for the rest of the paper, the assumption made by Sarmento and Brandao (2007) that $2\varphi - \beta^2 > 0$ also holds.

Considering the value of $I^R$, the retail price and the output of the firms are the following:

$$q_1^R = [2\varphi(1-c) + w\beta^2 - c\beta^2]/(4\varphi - \beta^2) \tag{11}$$

$$q_2^R = [\varphi(1+c) + w\beta^2 - 2w\varphi - c\beta^2]/(4\varphi - \beta^2) \tag{12}$$

$$P = [\varphi(1+c) + 2w\varphi - c\beta^2]/(4\varphi - \beta^2) \tag{13}$$

From Eqs. (10)-(13) it can be deduced that the NGA investment level, as well as, the output of the firms are affected by the access price $w$. This is an expected result since in "the regulator's approach" the regulator moves first and then the incumbent decides its optimal investment level.

Under cost-based regulation, the regulator defines the access price as the marginal cost of providing the access ($c$) plus a fraction ($a$) of the total investment cost, that is $w^R = c + aC(I)$, with $a < 1$. Like Sarmento and Brandao (2007), it is assumed that $a = (1/I)$, and hence, $w^R = c + (\varphi I/2)$. This definition implies that the regulator sets an access price equal to the marginal cost of providing the access plus the average cost of the investment.

Substituting $w^R = c + (\varphi I/2)$ in Eqs. (10)-(13) provides the final results under cost-based regulation:

$$q_1^R = \frac{\varphi(1-c)(4-\beta)}{2(4\varphi-\beta^2-\beta\varphi)} \tag{14}$$

$$q_2^R = \frac{\varphi(1-c)(2-\beta)}{2(4\varphi-\beta^2-\beta\varphi)} \tag{15}$$

$$q^R = \frac{\varphi(1-c)(3-\beta)}{4\varphi-\beta^2-\beta\varphi} \tag{16}$$

$$I^R = \frac{\beta(1-c)}{4\varphi-\beta^2-\beta\varphi} \tag{17}$$

**Assumption 2.** Let $4\varphi-\beta^2-\beta\varphi > 0$.

Assumption 2 is considered in order to ensure that $I^R > 0$. In addition, a necessary and sufficient condition for ensuring that both firms are active in the market (i.e. $q_1^R, q_2^R > 0$) is $\beta < 2$. Hence, the following assumption is made:

**Assumption 3.** Let $\beta < 2$.

The comparison of $I^I$ and $I^R$ shows that "the incumbent's approach" leads to higher investment level than "the regulator's approach".[5] Concerning consumer surplus, the comparison of the "regulator's" and the "incumbent's" approaches shows that the latter leads to a higher consumer surplus than the former if $3\beta > \varphi$.[6] Therefore, the consumers prefer the incumbent to decide prior to the regulation of the access price when the investment cost function is increasing and convex but not excessively convex in relation to the impact of the investment on demand. If, on the contrary, $3\beta < \varphi$, consumers would prefer the regulator to set the access price at cost before the incumbent decides its investment level. This is a reasonable result because the optimal investment is higher under "the incumbent's approach". Therefore, if the slope of marginal cost of the investment cost function is excessively steep in relation to the impact of the investment on demand, the incumbent's overinvestment is not socially desirable. Last, it is obvious that both approaches avoid foreclosure when the access is regulated at cost.

### *5.2. Discussion*

The comparison of the results obtained by "the incumbent's approach" with those obtained by "the regulator's approach" shows that although it is ambiguous which approach leads to better results in terms of consumer surplus, "the incumbent's approach" leads to better results than "the regulator's approach" in terms of investment level.

This is an unexpected result since the obtained NGA investment level is higher under regulatory uncertainty than under credible regulatory commitments. The reason of this striking result is that although "the incumbent's approach" assumes regulatory uncertainty about the future regulatory policy, the incumbent undertakes such uncertainty by investing in NGA networks even if it is not

[5] See proof in Appendix A1.

[6] See proof in Appendix A2.

reimbursed for such uncertainty. On the contrary, under no regulatory commitment problem, the optimal NGA investment level is lower because the incumbent does not undertake the regulatory uncertainty when it is not reimbursed for such uncertainty. It can be thus concluded that if the regulator announces a cost-based access price that incorporates a risk premium reflecting the regulatory uncertainty and then the incumbent choose its optimal NGA investment level, the derived level of the NGA investment will equal that of the “the incumbent’s approach”. We will call the former approach as “the regulator’s approach with risk premium” since it assumes that the regulator first announces an access price scheme that compensates the incumbent for the regulatory uncertainty, and then the incumbent makes its optimal investment decision.

In the following section, we derive the risk premium that equates the investment levels obtained by “the incumbent’s approach” and “the regulator’s approach with risk premium” under cost-based access rules. The obtained risk premium reflects the regulatory uncertainty that the incumbent incurs when investing in NGA networks. Not surprisingly, “the regulator’s approach with risk premium” leads to a higher investment level than “the regulator’s approach”. However, it should also lead to better results in terms of consumer surplus in order to be the chosen regulatory policy. Otherwise, there will be another regulatory trade-off between encouraging investments and promoting competition. Thus, we also provide the specific conditions under which the incorporation of a risk premium into the access price is beneficial for the consumers.

### *5.3. Access pricing with risk premium*

This section studies the impact of the incorporation of a risk premium into the access price on investment level and total output. The risk premium should compensate the incumbent for its forgoing investments due to the regulatory uncertainty. As noted earlier, the risk premium that the regulator incorporates into the access price should equate the investment levels derived by “the incumbent’s approach” and “the regulator’s approach with risk premium”. Or, in other words, the incumbent should be indifferent between investing prior or after the access regulation stage.

Under cost-based regulation with risk premium, the regulator defines the access price as in section 5.1. plus a premium over this access price. Then, $w^{RP} = (c + \varphi I / 2)(1 + y)$, where $y$ represents the risk premium. Substituting this access price into Eq. (10) gives the incumbent’s investment level as a function of $y$:

$$I^{RP} = \beta(1 - c + 2cy) / (4\varphi - \beta^2 - \beta\varphi - \beta\varphi y) \tag{18}$$

Equating $I^{RP}$ with $I^{I}$ and solving with respect to $y$ gives the level of the optimal risk premium:

$$y = \frac{2\varphi^2(1-c)(2-\beta)}{\beta(\varphi^2 + c\varphi^2 + \beta\varphi + 8c\varphi - 2\beta^2 c - 5\beta c\varphi)} \tag{19}$$

Considering Eq. (19), the final results of the cost-based regulation with risk premium are the following:

$$q_1^{RP} = \frac{\varphi(1-c)(4-\beta+\varphi)}{2(4\varphi - \beta^2 - 2\beta\varphi + \varphi^2)} \tag{20}$$

$$q_2^{RP} = \frac{\varphi(1-c)(2-\beta)(\beta-\varphi)}{2(4\varphi-\beta^2-2\beta\varphi+\varphi^2)} \tag{21}$$

$$q^{RP} = \frac{\varphi(1-c)(3\beta+\beta\varphi-\varphi-\beta^2)}{\beta(4\varphi-\beta^2-2\beta\varphi+\varphi^2)} \tag{22}$$

$$I^{RP} = \frac{(1-c)(\beta+\varphi)}{4\varphi-\beta^2+\varphi^2-2\beta\varphi} \tag{23}$$

**Assumption 4.** Let $4\varphi-\beta^2-2\beta\varphi+\varphi^2>0$**.**

Assumption 4 guarantees that the investment level under cost based regulation with risk premium is positive. Not surprisingly, this investment level is the same with the investment level obtained by "the incumbent's approach". For this reason, Sarmento and Brandao (2007) also make this assumption. In addition, a necessary and sufficient condition for ensuring that the entrant is active in the market is $\beta>\varphi$. If, on the contrary, $\beta\le\varphi$ the cost-based access regulation with risk premium forecloses the entrant from the downstream market. It is obvious that in this case the regulator should not incorporate into the access price such a high premium as $y$. For the rest of this section it is assumed that $\beta>\varphi$.

Therefore, the regulator should compare $q^{RP}$ and $q^{R}$ in order to decide whether or not the incorporation of a risk premium into the access price is the optimal policy. If the incorporation of risk premium leads to both higher investment level and total output, the regulator should set the access price at the level described by $w^{RP}$. The comparison of $q^{RP}$ and $q^{R}$ shows that the incorporation of $y$ into the access price leads to higher total output (and then to higher competition level) if $\beta^2>\varphi$**.**[7] The regulatory implications of the analysis concerning the cost-based regulation can be summarized in the following proposition:

**Proposition 1.** *Under cost-based regulation, the optimal regulatory policy is: (i) to set the access price at* $w^{RG}$ *if* $\varphi<\min\{\beta,\beta^2\}$*; and (ii) to set the access price at* $w^{R}$ *if* $\varphi>\min\{\beta,\beta^2\}$*.*

From Proposition 1, it is deduced that the regulator should incorporate a risk premium into the access price when $\varphi<\min\{\beta,\beta^2\}$. This policy leads to higher investment level and consumer surplus than access price regulation without risk premium, while it ensures that the incumbent does not foreclose the entrant from the market. However, if $\beta\le\varphi<\beta^2$, "the regulator's approach with risk premium" results in both higher investment and consumer surplus level that the "the regulator's approach" but forecloses the entrant. In addition, if $\beta^2<\varphi<\beta$, there is a trade-off between encouraging investments and promoting competition. The reason is that a higher access price leads to a higher investment level and to lower consumer surplus. In these cases, a benevolent regulator whose primary goal is to enhance competition should set the access price at $w^{R}$. However, the

[7] See proof in Appendix A3.

benevolent regulator may also wait for the incumbent to undertake the risk of regulatory uncertainty if $\varphi < 3\beta$. This implies that the incumbent invests before the regulation of the access price and such policy is optimal since it results in better outcomes that the “regulator’s approach” in terms of both investment level and consumer surplus.

## 6. Conclusions

The aim of this paper was to derive the optimal risk premium that reflects the regulatory uncertainty incurred by investing in NGA networks. Thus, we compared the NGA investment levels obtained when the incumbent invests under regulatory certainty and under regulatory uncertainty.

When the incumbent chooses its optimal NGA investment level prior to the regulation of the access price which does not incorporate any risk premium reflecting the uncertainty about future regulatory intervention, it implicitly undertakes such risk since it chooses to invest. Therefore, although the incumbent invests under regulatory uncertainty, it does not take such uncertainty into account. Based on these assumptions, Sarmento and Brandao (2007) studied the impact of deregulation, cost-based regulation and retail-minus regulation on NGA investment level, consumer surplus and foreclosure of the entrant from the retail market. On the contrary, when the incumbent considers the regulatory uncertainty when determining its optimal NGA investment level, it chooses to invest after the regulation of the access price. We explored the robustness of the results of Sarmento and Brandao (2007) under the assumption that the incumbent invests in NGA networks after the regulation of the access at cost-based prices.

The comparison of the two approaches showed that cost-based regulation makes the incumbent underinvest if it considers the regulatory uncertainty when it deploys an NGA network. Therefore, the incorporation of a risk premium that reflects the regulatory uncertainty into the access price would make the incumbent choose the NGA investment level derived under regulatory uncertainty. We derived the risk premium that equates the NGA investment levels obtained by the approach of Sarmento and Brandao (2007) and the approach presented in this paper which incorporates a risk premium. Thus, the derived risk premium reflects the regulatory uncertainty of the investments in NGA networks.

However, it is widely known that the regulator’s goal is not only to encourage efficient and timely investments in NGA networks, but also to promote effective competition. Thus, we also provided the condition under which the incorporation of a risk premium into the access price increases both NGA investments and competition. In particular, when the slope of the marginal cost function of the investment is significantly but not extremely steep (i.e. $\beta^2 > \varphi$), then a higher access price benefits both the incumbent and the consumers. Therefore, the incorporation of a risk premium into the access pricing formula is the optimal regulatory policy providing that it does not foreclose the entrant form the retail market.

It should be noted that the derived outcome is aligned with the current regulatory practice in the European NGA market since the access price reflects the cost of providing the access including a markup for the demand and the regulatory uncertainty of NGA investments. Therefore, we showed that, under plausible assumptions and specific conditions, cost-based access rules can tackle the regulatory trade-off between encouraging efficient NGA investments and promoting effective competition. However, the authors already study the impact of other regulatory instruments (such as deregulation and retail-minus regulation) on foreclosure, investment level and consumer surplus in order to compare their efficiency with that of cost-based regulation.

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## Appendix A

We assume that regardless of the timing of the game, the investment level, the incumbent's output and the entrant's output are positive under cost-based regulation. Therefore:

A.1

The condition $I^I > I^R$ is equivalent to $I^I - I^R > 0$. From Eqs. (6) and (17) in the text, we have:

$$\frac{(1-c)(\beta+\varphi)}{4\varphi-\beta^2+\varphi^2-2\beta\varphi} - \frac{\beta(1-c)}{4\varphi-\beta^2-\beta\varphi} > 0 \Rightarrow$$

$$\frac{2\varphi^2(1-c)(2-\beta)}{(4\varphi-\beta^2-\beta\varphi)(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} > 0$$

which always holds.

A.2

The condition $q^I > q^R$ is equivalent to $q^I - q^R > 0$. From Eqs. (5) and (16) in the text, we have:

$$\frac{\varphi(1-c)(6+\varphi-2\beta)}{2(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} - \frac{\varphi(1-c)(3-\beta)}{4\varphi-\beta^2-\beta\varphi} > 0 \Rightarrow$$

$$\frac{\varphi^2(1-c)(2-\beta)(3\beta-\varphi)}{2(4\varphi-\beta^2-\beta\varphi)(4\varphi-\beta^2+\varphi^2-2\beta\varphi)} > 0$$

which holds for $3\beta > \varphi$.

A.3

The total output, $q$, is the sum of the incumbent's and the entrant's output, $q_1$ and $q_2$, respectively. Adding Eqs. (11) and (12) gives the total output as a function of the access price, i.e. $q^R = (3\varphi - \varphi c + 2w\beta^2 - 2w\varphi - 2c\beta^2)/(4\varphi - \beta^2)$. A marginal increase in $w$ due to the incorporation of the risk premium causes a change in the total output by $2(\beta^2 - \varphi)$. Thus, if $\beta^2 > \varphi$, the incorporation of a risk premium into the access prices leads to higher total output and hence to higher consumer surplus (competition) level. In addition, the comparison of $q^R$ and leads to the same result.

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# Two-way interconnection, competition and investment incentives: A survey of the economic literature

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Abstract—This paper surveys the broad literature of two-way interconnection. In particular, it discusses how different assumptions concerning retail pricing strategies, demand structures, network externalities and asymmetries in the market affect the impact of termination charges on competition and investment incentives. The main contribution of this paper is that it points out the cases that have not been fully studied yet or the related literature provides mixed results.

Keywords—competition; interconnection; termination charges; two-way access

# I. INTRODUCTION

The deregulation of most telecommunications markets has challenged the need for regulatory intervention. In the case of one-way access, an unregulated incumbent may charge a too high access price in order to foreclose the access seekers (entrants) from the retail market. Therefore, the regulatory intervention in the access market is necessary for establishing competition, especially at the earlier stages of deregulation. On the contrary, in the case of two-way access, the operators have a mutual incentive to interconnect their networks in order to serve calls originated on their networks and terminated on competing networks. Therefore, although each operator is a monopolist over its subscribers' access lines, regulators are still concerned about the need to regulate termination charges (or access prices or interconnection charges).

Indeed, the economic literature on two-way interconnection provides ambiguous results concerning the impact of negotiated termination charges on the competition outcome in an unregulated access market. The seminal papers of this literature are those of Laffont, Rey and Tirole [1] and Armstrong [2], hereafter A-LRT. These papers show that interconnection charges between two unregulated competing networks can be used to facilitate collusive outcomes. In particular, A-LRT show that under linear retail tariffs high interconnection charges reduce each network's incentives to lower retail price in order to increase market share.

The reason is that if either network decreases its retail price, its subscribers will make more calls which triggers a net outflow of calls. Therefore, with termination charges above marginal cost, the incentive to decrease retail prices is reduced and the retail competition is softened. This implies that networks find it profitable to collude over the access charge in an unregulated market.

On the contrary, two-part tariffs (i.e. introducing a fixed charge into the linear retail pricing formula), which is a particular pricing scheme of non-linear pricing, make the two networks indifferent over the termination charges (profit neutrality) [1]. The basic intuition of this result stems from the fact that the fixed fee provides the networks with an additional instrument to build their market shares. Therefore, when the termination charge is increased, firms will increase call prices but, at the same time, they will reduce the fixed component to keep market shares. This implies that collusion over termination charges is unsustainable since each network sets the usage access fee at its perceived marginal cost (in order to avoid an access deficit) and uses the fixed fee to build market share.

It is thus obvious that the results are significantly sensitive to the assumption about the structure of the retail tariffs. However, since the benchmark A-LRT model is not only based on the assumption of linear retail prices, but also on many other assumptions, the robustness of the collusive and the profit-neutrality outcomes should be explored when relaxing the underlying assumptions. In particular, the A-LRT framework assumes that: (i) the network operators set linear retail prices, (ii) there are two symmetric unregulated networks which compete in a standard Hotelling framework (hence, full consumer participation is also assumed), (iii) the termination charges are uniform (i.e per-minute and usage-based) and reciprocal (i.e. symmetric networks charge as much for terminating a call originated on the rival network as they pay for terminating a call on the rival network), (iv) the demand for calls is homogeneous (i.e. all consumers have the same demand for calls), (v) the retail pricing is non-discriminatory (i.e. network operators charge their subscribers the same retail price either if a call originated on a network will be terminated on the same network ("on-net call") or on a competing network ("off-net call"), (vi) only callers receive utility from a call (caller-pays principle) and (vii) there is a balanced calling pattern (i.e. the percentage of on-net calls is equal to the fraction of consumers subscribing to this network, which implies that for equal marginal prices, flows in and out of a network are balanced even if market shares are not).

This paper reviews the existing publications that extend the common A-LRT framework by relaxing some of the above benchmark assumptions. A first aim of this paper is to update previous reviews of the literature on two-way interconnection ([3], [4]) since these articles are published in 2002 and 2003, respectively, and as a result they only review the early publications. However, the main goal of this paper is to point out the cases that have not been studied yet or the related literature provides mixed results. Thus, each paper is classified according to its underlying assumptions. Table 1 classifies all the articles reviewed by this paper according to the way they depart from the benchmark A-LRT framework. Since the seminal papers derive the impact of termination charges on competition under linear and two-part tariffs in a symmetric environment, there are two ways to extend this framework. The first way is to study the robustness of the derived results when allowing for termination-based discrimination (i.e. price discrimination between on-net and off-net calls), consumer heterogeneity or network externalities (i.e. non-full consumer participation) in a symmetric environment. The second way is to examine whether the seminal results or the extended ones are robust in an asymmetric environment.

A much more significant extension is to study the impact of regulated termination charges on competition outcomes or to introduce an endogenous **investment** in quality. Each of these two assumptions can be combined with all the other assumptions that extend the A-LRT framework and hence each combination should be investigated separately. However, rather than presenting two more tables, we have italicized the papers that assume regulated termination charges and we have bolded the papers that introduce investment incentives.

TABLE I. CLASSIFICATION OF THE REVIEWD PAPERS ACCORDING TO THEIR UNDERLYING ASSUMPTIONS

| | | **SYMMETRIC OPERATORS (MATURE MARKET)** | | **ASYMMETRIC OPERATORS (EARLY STAGES OF DEREGULATION PROCESS)** | |
|---|---|---|---|---|---|
| | | **LINEAR TARIFFS** | **TWO-PART TARIFFS** | **LINEAR TARIFFS** | **TWO-PART TARIFFS** |
| **BENCHMARK ASSUMPTIONS (iii)-(vii)** | | [1], [2], *[33]*, *[34]*, *[35]* | [1], *[35]*, **[37]** | [5] | [6], [7], *[35]*, **[37]**, **[39]** |
| **TERMINATION-BASED DISCRIMINATION** | **ONLY CALLERS PAY** | [15] | [14], [15], [16], [17] | | [18], [19], **[38]** |
| | **CALLERS &RECEIVERS DERIVE UTILITY BUT ONLY CALLERS PAY** | [20] | [21] | [22] | [22] |
| | **BOTH DERIVE UTILITY-BOTH PAY** | [23], [24], [25], [26], [30] | [23], [24], [25], [26], [27], [30] | | [28] |
| **CONSUMER HETEROGENEITY** | | | [8], [9], [10], [11], [12], *[35]* | | [13] |
| **NETWORK EXTERNALITIES (PARTIAL PARTICIPATION)** | | | [8], [31], [32] | | |

From table I it can be concluded that the impact of termination charges on competition has been adequately studied in the cases where two either symmetric or asymmetric network operators charge two-part (discriminatory) retail prices. In addition, although there are several papers that study the impact of consumer heterogeneity and network externalities on the collusive and profit-neutrality outcomes with two-part tariffs, the related literature does not provide any result when asymmetries and/or linear tariffs are taken into account. Most significantly, the literature has not studied the impact of alternative regulatory settings that departs from the standard termination charges when relaxing the benchmark assumptions. Last, although regulators aim at not only promoting competition but also at encouraging investments, the relationship between termination charges, competition and investments has not been fully investigated. In particular, the related literature has studied this relationship only with two-part tariffs and only for one deviation from the benchmark assumptions (termination-based discrimination when only callers receive utility from calls).

Therefore, table I can be used as a motivation for future research on the fields that the related literature provides few or no results. Section II reviews the existing publications that extend the common A-LRT framework and examine the robustness of the collusive and the profit-neutrality outcomes when departure from the benchmark assumptions. It is obvious that future research is also needed when the related literature provides mixed results. The last section concludes the main results of the literature of two-way interconnection.

## II. LITERATURE REVIEW

This section reviews the literature that studies the robustness of the collusive and the profit-neutrality outcomes when the benchmark assumptions of the A-LRT framework are relaxed.

### *A. Asymmetric market structure*

A first significant extension of the A-LRT framework is to allow for asymmetry between the two networks. This case better corresponds to the earlier stages of the deregulation process of the telecommunications market where the incumbent has several advantages over the (potential) entrants in terms of cost and demand. Allowing for unequal-sized networks by providing for brand loyalty, shows that the ability to use interconnection charges to facilitate collusion is retained with asymmetry [5]. However, the profit-neutrality outcome vanishes when asymmetric networks charge two-part tariffs [6]. In particular, the incumbent prefers the reciprocal access charge to be set at the marginal cost of providing the local loop, whereas the entrant prefers to have below (above) cost access charges when it faces a net outflow (inflow) of calls. If the two networks cannot agree on the level of interconnection charges, the regulator should require that the incumbent and entrant interconnect at some reciprocal price, but leave the incumbent free to set this price. The reason is that cost-based interconnection charges achieve the welfare maximizing outcome without any need for the regulator to determine costs or prices. If networks set non-reciprocal interconnection prices, then each firm prefer to unilaterally increase their charge for local call interconnection. In this case, non-reciprocal interconnection agreements allow the incumbent to use its greater bargaining power to charge more for incoming calls than it pays for outgoing calls. This can act as a barrier to entry for competitors to the extent it is not justified by cost differentials.

Therefore, when asymmetries call for non-reciprocal interconnection charges, the primary aim of access regulation should be the promotion of competition. According to [7], an access regulation scheme that provides the incumbent with cost-based termination charges and gives a positive access markup to the entrant has two positive effects on competition: a potential entrant is more likely to enter and, given entry, competition is more intense. Hence, this type of wholesale price regulation is effective in protecting consumers and encouraging entry at the same time. However, it also leads to a loss in total surplus which arises from a distorted per-minute price by the incumbent. It should be noted that this policy recommendation holds under both linear prices and two-part tariffs.

### *B. Consumers heterogeneity*

It is shown that the profit-neutrality outcome still holds when customers are heterogeneous and networks engage in non-linear retail pricing[1] [8]. This result

[1] In this section, we use the general term “non-linear pricing” because the networks also price-discriminate among the different types of customers.

suggests that the optimal regulatory policy is to recommend networks set their access charge equal to the marginal termination cost [9]. Provided competing networks are symmetric, the firms have no strict incentive not to follow the recommendation. Then, with access charges being equal to costs the equilibrium tariff is a simple cost-based two-part tariff, resulting in efficient call-allocations for all types of consumers. On the contrary, when the A-LRT framework is modified in order to capture the fact that there might be a time frame after the deviation period where the cartel firms can react by changing the retail tariff but not by adjusting the termination charge, then termination fees can support collusion in the retail market even under two-part tariffs [10]. The reason is that with heterogeneous consumers, the optimum deviation strategy is usually to try to attract the high valuation customers since they are the ones with the highest profits. This strategy is made less attractive by setting termination fees above cost, since a deviator with a pool of high users will have more outgoing than incoming calls. Therefore, termination fees above marginal cost reduce the deviation profits and stabilize the collusion. The same outcome is reached when assuming that with high access prices (and so high retail prices) low demand users would not necessarily want to participate [11]. In particular, if there is a call imbalance between the two sectors, firms can set an access charge so that high demand customers generate an access revenue deficit. The effect of this is to limit competition for high demand customers and increase competition for light users.

From the above analysis, it can be deduced that introducing consumer heterogeneity in the A-LRT model with non-linear tariffs yields different results depending on the underlying assumptions. This analysis becomes much more complex if we take into account that customer heterogeneity in outgoing volume demand is not only correlated with differences in incoming call volume, but also with differences in how customers perceive competing networks. In particular, different customer types are likely to perceive the substitutability of the networks differently as they have different switching costs, different brand loyalty or a differentiated access to publicity and information about the networks. When networks are seen as better substitutes by the heavy (light) users than by the light (heavy) users, networks obtain higher profits by agreeing on an access charge below (above) marginal cost [12]. Therefore, the standard neutrality of two-way access prices found in the earlier literature no longer holds.

The only paper that discusses the impact of termination charges on competition between two asymmetric networks when subscribers are heterogeneous in their demand for calls is [13]. It shows that an increase in the incumbent's (entrants') termination charge leads the entrants to increase (decrease) their prices to all subscriber groups. An equal increase in both termination charges leads the entrants to lower their prices to low-volume users and raise their prices to high-volume users. Hence, the difference between termination charges affects the average intensity of competition, while an increase in the average termination charge affects the relative intensity of competition for the high and low volume subscribers. Concerning the optimal regulatory policy, it is shown that a reciprocal termination charge is optimal as long as the incumbent is regulated so that it just breaks even. This reciprocal charge is above the incumbent's cost of access whenever its retail tariff involves subsidizing low volume users.

*C. Termination-based price discrimination*

The most important extension of the A-LRT model is to allow the networks to price-discriminate according to whether a call originated on one network is terminated on the same network (on-net) or on a rival network (off-net). The reason is that such a pricing strategy is widely used in the typical two-way markets, such as mobile communications and internet services. The related literature is mainly focuses on two-part tariffs since the pricing structures are non-linear in these markets.[2] Therefore, under price-discrimination and two-part tariffs, networks would like to agree on a reciprocal termination charge below marginal cost in order to relax downstream competition [14]. In such cases, off-net calls are cheaper than on-net calls and hence networks compete less aggressively for market share. This result corrects the argument that termination charges are negotiated to equal the marginal cost of terminating a call provided by [15]. The conclusion of [14] that networks are interested in setting the access charges below cost to soften competition is not altered when generalizing to the multi-firm case [16]. However, when allowing for networks to choose competitively non-reciprocal access prices, it is shown that optimal access charges exceed the cost of termination [17].

There are two papers that study the impact of termination charges on competition between two asymmetric networks when they can set different two-part tariffs for on-net and off-net calls. The first paper assumes a reciprocal access price and shows that departing from cost-based access pricing allows the incumbent to foreclose the market in a profitable way [18]. This result depends on the impact of switching costs on consumers' ability to switch between networks. If the incumbent benefits from customer inertia, then it has an incentive to insist in the highest possible access markup even in the absence of actual switching costs. If instead the entrant benefits from customer activism, then foreclosure is profitable only when switching costs are large enough. The second paper shows that granting an access markup to the entrant reduces the probability of foreclosure and hence intensifies competition [19]. Therefore, non-reciprocal access prices that favor the entrant increase the entrant's profits and consumer surplus but decrease social welfare. The reason for their positive effect on entrant's profits and consumer surplus is that an increase in the access price paid by an operator is passed on to consumers through an increase of the per-minute price of off-net calls (which obviously benefits the entrant). On the contrary the reason for their negative impact on total surplus is that the off-net price of the strong operator is distorted above the socially efficient level and the market share of the strong operator is distorted further below the socially efficient level.

All the above studies assume that only the caller benefits from a call and not the receiver. The following three papers allow both callers and receivers to receive utility from a call (namely call externalities). In such cases consumers care about being called and hence networks set higher off-net prices in order to make the rival network less attractive. This implies that access charges below marginal cost can be used as a collusion device [20]. It is also shown that the welfare maximizing access charge is below the one that maximizes industry profits. Under two-part tariffs both the collusive and the welfare maximizing access charges also fall below marginal cost [21]. Therefore, call externalities do not alter

[2] In fact, this retail pricing scheme can been seen as a three-part tariff since it consists of a fixed fee and two usage fees for the on-net and the off-net traffic, respectively. However, the related literature calls this pricing scheme as two-part tariffs.

the main result of termination-based price discrimination provided by [14]. In the case of asymmetric networks, the structure of retail pricing (i.e. linear or two-part tariffs) does not affect the incumbent's incentives to set higher off-net prices. This implies a higher off-net/on-net differential which leads the entrant to incur a permanent access when the reciprocal access charge is above marginal cost. In addition, the incumbent can adopt an anti-competitive, predatory-pricing strategy aimed at foreclosing the entrant. Predatory behavior would be accompanied by even larger on-net/off-net differentials even if access charges are set at cost [22]. Therefore, the presence of call externalities can lead the incumbent to foreclose the entrant, whereas in the absence of call externalities the incumbent can foreclose the entrant when the former benefits from customer inertia [18].

Another set of papers not only allow for call externalities and termination-based price discrimination but also assume that both callers and receivers share the cost of a call (i.e. networks charge both callers and receivers). This literature analyzes the effects of termination charges on retail prices when networks can set four separate per minute usage rates: an off-net origination rate, an off-net termination rate, an on-net origination rate and an on-net termination rate. The literature has produced two differing results concerning the effect of access charges on usage retail rates. The first result is widely known as "the off-net cost pricing principle (ONCPP)", which argues that all on-net and off-net usage rates will equal the marginal cost of providing service plus (minus) access charges paid (received) [23], [24]. The second result concludes that on-net rates depend only on (efficiently allocating) the on-net costs of service, while off-net rates depend both on the costs of providing the service and the access rate [25]. It is shown in [26] that these different results depend on different assumptions regarding: (i) how usage rates affect consumer usage, (ii) whether subscribers to a telephone network both originate and receive calls, and (iii) whether some customers only originate calls while others only receive calls. Specifically, when customer usage does not depend on usage rates, and some customers originate all of the calls in which they engage while other customers receive all of the calls in which they engage, then the ONCPP will tend to describe the equilibrium. On the other hand, when the number of minutes of calling in which a customer engages depends on usage rates and customers tend to originate about the same number of minutes as they receive, then on-net rates tend to reflect only the cost of providing on-net service.

The literature studying the impact of termination charges on retail prices when both callers and receivers pay for the utility they derive is based on the assumption that there is a fixed volume of transactions for each receiver-caller match and all calls deliver the same gross surplus to a given end user. Thus, the distinction between linear and non-linear tariffs is irrelevant. However, a much more general determination of the ONCPP shows that when volume is variable, the marginal cost perceived by each network is affected by the externalities on the rival network's subscribers, and this leads networks to charge prices equal to off-net costs while, when volume is fixed, there are no such externalities [27].

A significant problem emerges when the receiver of a call benefits by as much as, or more than, the sender. In this case, both networks set off-net call charges so high as to eliminate off-net calling altogether. Even when the reciprocal termination charge is set equal to marginal cost, equilibrium off-net call charges still exceed the efficient level and a connectivity breakdown emerges [27]. This result also holds when allow for asymmetric networks [28]. However, the probability of a connectivity breakdown is reduced when calls made and received are complements in the information exchange [29].

Another problem concerns the necessity of reciprocal access prices for the existence of equilibrium [24]. In addition, symmetric access charges ensure the robustness of the ONCPP in an industry with any number of competing networks. Allowing for asymmetric but reciprocal access pricing in the presence of an arbitrary number of network operators shows that if the reciprocal access charge of a pair of networks departs away from a given symmetric access charge, then the two networks are driven out of one side of the market [30].

### *D. Partial consumer participation*

Another significant deviation from the basic A-LRT framework is to relax the “full consumer participation principle” of the Hotelling model. Therefore, the demand for calls is elastic, some customers choose not to subscribe and the industry exhibits network externalities. This implies that networks should take into account the market expansion effects, as well as, the business stealing effects of their pricing strategies.

In particular, symmetric network operators may increase their profits by agreeing on an access charge below the marginal cost of access when they charge the callers with two-part tariffs [8]. This result removes the idea that the collusion concern should be associated with high access charges and confirm the results of [14]. Therefore, one may conclude that allowing for either partial participation or network-based price discrimination results in a reciprocal below cost access charge which vanish the profit-neutrality outcome of [1].

However, as it is shown in [31] a fixed participation rate makes the networks indifferent over the level of the access charge. On the contrary, an endogenous participation rate is crucial for the non-neutrality of the access charge. In particular, the profit maximizing access charge is also below marginal cost. As in the full participation case, the access charge can be used to manipulate equilibrium per-minute prices and rentals. Below cost termination charges make additional consumer less attractive (i.e. softens competition), but competition in rentals is even more fierce because there are new customers outside the market to be competed for, as well as, existing customers. It can be thus deduced that whether the profit-neutrality outcome still holds under partial participation depends on the endogeneity of the participation rate.

A very significant finding is provided by combining partial participation and network-based price discrimination. As it has been already mentioned in [8] and [14], higher than cost-based access charges induce stronger competition when networks can price-discriminate or there exist network externalities, respectively, and hence networks prefer below cost access charges. However, when both price discrimination and network externalities are present, network operators have an incentive to set the access charge above marginal costs of termination in order to increase joint market coverage and thereby exploiting network effects [32]. This strategy is in line with the maximization of social welfare and can hardly be called “collusion”. In fact, the welfare maximizing level of access charges is also above marginal costs of termination and may be higher or lower than the negotiated access charge.

*E. Regulation of the access price*

So far we have mainly focused on two unregulated networks which agree on a reciprocal termination charge. Now, we study the optimal regulatory policy that reduces the networks' incentives to collude over a reciprocal termination charge. Recall that in a symmetric equilibrium with linear tariffs access charge may be used as a collusive device if high access charges inflate retail prices [1]-[2]. Therefore, an efficient access pricing rule must not inflate retail prices. It is shown that the Generalized Efficient Component Pricing Rule (GECPR)[3] exhibits such a property, and induces a highly pro-competitive outcome for a wide range of parameters. The GECPR dominates the Efficient Component Pricing Rule (ECPR), marginal cost pricing, and any non-negative fixed access charges in terms of efficiency [33].

Another regulatory alternative is to deviate from per-minute (usage) termination charges in order to prevent collusive outcomes and market foreclosure that harm consumers. Specifically, in the case of partially collusive retail market, non-linear access prices that are cost-based, negatively sloped and based on per-consumer usage result in the social optimal outcome [34]. This result holds under the benchmark assumptions of the A-LRT model. However, as it is shown in [35], an access price which is a linear function of both marginal costs and (average) retail prices set by both networks, can lead to the most efficient outcome under different assumptions concerning retail pricing, consumer heterogeneity and asymmetries in the market. In particular:

(i) With linear retail prices, there is a unique rule that implements the Ramsey price outcome as an equilibrium, independently of the underlying demand conditions, as long as there exists at least a mild degree of substitutability between networks' services. Therefore, even if the regulator does not have any information about the demand structure, it can provide the social optimal outcome by increasing the competition level. The reason is that contrary to the results of [1] and [2], such an access pricing scheme promotes competition in retail prices since each network decreases its access payments by decreasing its retail price.

(ii) With two-part tariffs, there exists a class of rules under which firms choose the variable price equal to the true marginal cost. Therefore, the regulator can choose among these rules to pursue additional objectives, such as increasing consumer surplus or promoting socially optimal investment, while achieving the efficient outcome. The profit-neutrality outcome of [1] does not hold because a higher magnitude of the impact of the average retail prices on the access price intensifies competition in fixed fees. It should be noted that the marginal cost pricing result holds even for asymmetric networks.

(iii) Contrary to [8] and [9] which show that efficiency is achieved by making the case with interconnection identical to the case without interconnection (i.e. setting the access price equal to the marginal cost), an access price which is a linear function of both marginal costs and (average) retail prices can achieve efficiency (under a class of access pricing rules) in the presence of interconnection and consumer heterogeneity.

[3] The GECPR resembles the ECPR in that it also determines access charges based on the incumbent's opportunity cost. But the GECPR measures the opportunity cost in terms of the entrants' retail price instead of the incumbent's retail price.

*F. Investment incentives*

It is obvious that the primary goal of regulators is to promote effective competition in order to achieve static efficiency. Indeed, the question of the impact of two-way interconnection on static efficiency had been adequately investigated from the advent of the seminal works on 1998 until 2003, when it was first stated that there had not been developed any analysis of the linkage between access pricing and investment incentives [36]. The necessity of studying such linkage stems from the fact that the aim of regulators is not only to promote effective competition among network operators, which leads to lower prices and higher consumer surplus, but also to encourage efficient and timely investments by all networks, which leads to innovation and economic growth. However, the regulators' two-fold goal is related to the common trade-off between static and dynamic efficiencies.

In a two-way interconnection framework, the benchmark model of A-LRT is extended in order to allow networks to make quality-enhancing investments. An obvious reason for undertaking such costly investments is that they increase the consumers' willingness to pay and hence networks' profits. However, the related literature also studies whether such investments can be used as an instrument of "tacit collusion".

A starting point for answering such question is to keep in mind that quality-upgrading investments can reflect an endogenous asymmetry. The reason is that when competing networks choose different levels of investment, they face different demand and cost structures. Therefore, contrary to the results provided by an exogenous asymmetry under two-part tariffs [6], the networks have an incentive to agree to termination charges above the respective marginal cost since this strategy softens the competition over investments [37]. Therefore, in this case, the collusive outcome stems from diminishing each other's incentives to invest rather than raising each other's cost. It is obvious that this result is detrimental to social welfare and hence freely negotiated interconnection charges do not achieve the welfare maximizing outcome. This result is in stark contrast with the result obtained without quality-upgrading investments as provides by [6]. Since the above collusive outcome also holds in a symmetric equilibrium, the profit-neutrality outcome of two-part tariffs does not hold when quality-upgrading investments are taken into account.

A further extension is to examine whether termination-based price discrimination affects the under-investment result when termination charges have an impact on networks' investment incentives. It is found that when quality is regarded as exogenous factor, the results of [14] still hold even in an asymmetric environment. This implies that networks prefer to agree on a reciprocal termination charge below marginal cost in order to relax downstream competition. However, when quality-upgrading investments are endogenized, networks increase their profits by agreeing on above-cost reciprocal termination charges that diminish investment incentives [38]. Therefore, the under-investment result found in [37] is robust under termination-based price discrimination.

The aforementioned papers that study the impact of termination charges on networks' investment incentives explicitly assume that a quality-upgrading investment increases the consumers' willingness to pay, but does not alter their calling patterns. Allowing for a quality-sensitive traffic does not affect the main conclusion of this literature that private and social preferences always diverge once investments are endogenized [39].

## III. CONCLUSIONS

This paper provided a review of the economic[4] literature of two-way interconnection. The existing publications are mainly based on the seminal works of this literature which found that: (i) under linear retail pricing firms use above-cost reciprocal interconnection charges as an effective tool to soften competition in the retail market (collusive outcome), and (ii) under two-part tariffs interconnection charges have no effect on network operators' profits and hence collusion over termination charges is unsustainable (profit-neutrality outcome).

However, both results are based on particular assumptions concerning retail pricing strategies, asymmetries in the market, demand structures and network externalities. The literature that followed the advent of the seminal works mainly focused on exploring the robustness of the two main results when relaxing these benchmark assumptions.

It was found that the collusive outcome seems to be robust in asymmetric markets, as well as, under call externalities. However, in the latter case call externalities make the firms use below-cost reciprocal interconnection charges as an effective tool to soften competition in the retail market. Concerning the profit-neutrality outcome, it was concluded that this outcome still holds under consumer heterogeneity but it vanishes either in asymmetric markets or under termination-based discriminatory pricing.

In many cases, the collusive outcome can be achieved even with two-part tariffs. The detrimental effect of a collusive outcome on competition can be exacerbated when asymmetries in the market call for non-reciprocal access prices. In such cases the incumbents can use their greater bargaining power to foreclose the entrants from the retail market. Although the need for regulation is imperative in both cases, the related literature has not adequately investigated the impact of termination charges on competition. In addition, there are only few papers proposing different regulatory settings that prevent network operators from using the termination charges as an effective tool for collusion.

Most importantly, network operators can also agree on termination charges above marginal cost in order to soften competition over investments. This collusive behavior makes operators to under-invest which leads to both static and dynamic inefficiencies. Since private and social preferences always diverge once investments are endogenized, regulators should intervene in the access market in order to promote competition and encourage investments. Although this is a very interesting and challenging result, the relationship between access regulation, competition and investment incentives has been investigated in very few ways.

It is thus obvious that this paper not only reviewed the existing literature of two-way interconnection, but also pointed out the fields that the future research should focus in order to deal with the currently open issues. These fields include the investigation of the robustness of the two seminal results in cases where: (i) the existing literature provides few or no results (see table I), (ii) the existing literature provides mixed results, and (iii) the regulatory intervention is imperative

[4] We intentionally neglected technical aspects of interconnection (such as differences between circuit and packet switching technologies) since we aimed at discussing the impact of access charges on retail competition from an economic perspective.

in order to deal with anti-competitive practices and encourage efficient investments.

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# Flexibility or certainty? A regulatory dilemma

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*Abstract*

The aim of this paper is to examine the impact of regulatory uncertainty on an incumbent's incentives to invest in NGA and on the subsequent downstream competition level. Thus, it proposes a method for calculating the regulatory uncertainty and incorporating it into the access pricing formula. Two cases are discussed according to whether the regulator discloses the access pricing formula after the announcement of the regulatory period (maximum regulatory intervention) or the formula is of common knowledge (minimum regulatory intervention). It is found that in both cases there is a trade-off between encouraging NGA investments and promoting effective competition. Therefore, it is assumed that the regulator sets the regulatory period at the level that maximizes social welfare. The comparison of the derived results shows that the regulator should provide minimum than maximum regulatory intervention since the former policy leads to better results in terms of investments, competition and social welfare.

*Keywords*

access regulation, competition, investment incentives, regulatory uncertainty

## 1. Introduction

The migration from copper telecommunications networks to fibre-based next-generation access networks (NGA) capable of providing high-speed broadband services has induced a growing interest in the linkage between access regulation and investment incentives. The related literature concludes that there is a trade-off between encouraging investments and promoting effective competition.[1]

On the one hand, cost-oriented access prices provide the entrants with significant incentives to enter the market. Therefore, the consumers enjoy the benefits of effective competition, such as lower prices and higher quality. The main drawback of this approach, however, is that deters the incumbents from investing in network upgrade (Cave and Prosperetti, 2001; Jorde et al., 2000; Ingraham and Sidak, 2003) and encourages entrants to deviate from socially optimal investment level and to delay investments in alternative infrastructures (Jorde et al., 2000; Bourreau and Dogan, 2005). On the other hand, higher access prices incentivize the incumbents to invest in network upgrade but bear the risk of distorting competition and providing the entrants with incentives to build inefficient facilities to bypass the incumbent's network (Laffont and Tirole, 2000).

Given that the prospective investors in NGA networks are for large part the former incumbent operators (OPTA, 2010), the goal of regulators is to promote effective competition and encourage efficient and timely investments in NGA networks from the incumbents. For this reason, the European Commission (EC) issued a Recommendation on regulated access to NGA (EC, 2010) providing the National Regulatory Authorities (NRAs) with guidelines for tackling the trade-off between fostering competition and promoting investments with regard to NGA. In particular, the EC recommends calculating the access in a cost-based form that incorporates a risk premium. This premium should reflect any additional and quantifiable investment risk incurred by the investor.[2] According to OPTA (2008), the main factors that negatively affect the incumbent's incentives to invest in NGA networks are: (i) the uncertainty about future demand for new fibre-based services; and (ii) the regulatory uncertainty related to the regulator's limited ability to make *ex ante* credible commitments.

This paper focuses on the regulatory uncertainty and its impact on the regulator's two-fold goal to encourage NGA investments and to promote effective competition. Theoretically, the regulator can eliminate the regulatory risk if it fixes the principles of tariff regulation for the whole period of the economic lifecycle of an NGA investment. It is obvious that such a policy maximizes the regulatory certainty and provides the incumbent with significant incentives to invest in NGA networks. However, regulatory certainty bears the risk of erroneous intervention. An initial erroneous prediction for future industry profits, NGA penetration and technological changes may result in either incumbents' inability of recouping their investment costs or excessive prices that distort competition. According to WIK (2009), it is socially not optimal for the regulator to make *ex ante* commitments for an unreasonably long regulatory period. Therefore, in providing greater regulatory certainty the regulator has to make another trade-off between the positive effects of greater certainty on investment incentives and possible negative effects of erroneous intervention on welfare (OPTA, 2010).

[1] For a recent and comprehensive review of the related literature, see Cambini and Jiang (2009).

[2] For an extensive review of all the factors influencing the riskiness of an NGA investment project, see ERG (2009), pp. 17-18; WIK (2009), pp.1-7; and EC (2010), page 18.

In this paper, we use a simple method for calculating the risk premium that fully compensates the incumbent for the regulatory risk it incurs when investing in NGA, as well as, a similar method for incorporating such a risk premium into the access pricing formula. Then, we assess the impact of regulatory uncertainty on investment incentives, competition level and social welfare when: (i) the regulator discloses the access pricing formula after the announcement of the regulatory period; and (ii) the access pricing formula is of common knowledge. It is obvious that the first case requires "maximum regulatory intervention", whereas the second case requires "minimum regulatory intervention".

In addition, the former case poses an additional uncertainty concerning the ambiguity for the access pricing formula which is not compensated by the regulators. Thus, it is expected that the incumbent will choose a higher NGA investment level when the access pricing formula is of common knowledge rather than when the regulator discloses the access pricing formula after the announcement of the regulatory period.

The goal of this paper is to test the validity of the expectations regarding (i) the positive impact of a longer regulatory period; and (ii) the negative impact of an ambiguity for the access pricing formula, on the incumbent's incentives to invest in NGA networks. Based on the obtained results, this paper also assesses the impact of a longer regulatory period and the *ex ante* knowledge of the access pricing formula on the levels of competition and social welfare in order to make implications about the optimal regulatory policy that tackles the trade-off between encouraging investments in NGA networks and promoting efficient competition.

The rest of the paper is organized as follows. Section 2 gives an outline of the basic assumptions and definitions of the model. Sections 3 and 4 present the results obtained by maximum and minimum, respectively, regulatory intervention. Section 5 compares the results of the two regulatory approaches, whereas Section 6 conducts a risk and a sensitivity analysis in order to evaluate the impact of cost uncertainty and the uncertainty for the expected regulatory period on each period that maximizes investments, competition and social welfare. The last section summarizes the key findings and justifies regulatory implications.

## 2. The model

The aim of this paper is to examine the impact of the length of the regulatory period on NGA investment level, competition level and social welfare. We assume that the retail (downstream) market is characterized as an unregulated duopoly market in which an incumbent (the subsidiary firm of the upstream monopolist) and an entrant (the independent firm) compete á la Cournot. The inverse demand function is given by $p = A + X - (q_1 + q_2)$, where $p$ is the retail market price, $A$ is the reservation price when no investment has taken place, $X$ reflects the extent of NGA deployment undertaken by the incumbent and $q_1$ and $q_2$ are the quantities supplied by the incumbent and the entrant respectively.[3] Therefore, an increase in the level of NGA investment leads to higher consumers' willingness to pay. In other words, there is an outward parallel shift in the demand curve, which benefits both retailers.

[3] Nitsche and Wiethaus (2010) also assume Cournot competition in the retail market using the same inverse demand function.

The NGA deployment is continuous where a larger *X* reflects a fibre deployment closer to the consumers' premises and/or a larger geographic coverage within a given market area. The incumbent faces a quadratic NGA investment cost with respect to *X*, given by $c(X)=\gamma X^2/2$, with $\gamma>0$. The convex form reflects the fact that fibre deployment becomes marginally more expensive as (i) it is being laid down towards consumers' premises and/or (ii) it is extended to rural, less densely populated areas. It is further assumed that all the other costs of production and distribution are equal for both retailers and normalized to zero. Therefore, the profits functions of the incumbent (firm 1) and the entrant (firm 2) are given, respectively, by

$$\pi_1 = pq_1 + wq_2 - \gamma X^2/2 \qquad (1)$$

$$\pi_2 = (p-w)q_2 \qquad (2)$$

where *w* represents the access price paid by the entrant to the incumbent in order to have access to the local loop. The model described by Eqs. (1) and (2) is widely used in the literature of access regulation and investment incentives. However, it neglects the fact that the regulator's choice to provide greater flexibility or certainty affects both the NGA investment level and the access price.

It is assumed that the NGA investment level *X* corresponds to a particular certainty level resulted by the incumbent's assumption that the regulator will set the regulatory period at the expected (based on past experience) level. We denote this expected certainty level as *n*. Therefore, the NGA investment level *X* is obtained by the regulatory policy that sets the length of the regulatory period *m* equal to the expected one, i.e. *m*=*n*. If the regulator sets the length of the regulatory period *m* to a lower (respectively, higher) level that *n,* then it is expected that the NGA investment level will be lower (respectively, higher) than *X*. As a result, we can state that $X_R=(m/n)X$, where $X_R$ represents the NGA investment level that takes account of the regulatory uncertainty.

However, the regulator's choice to provide greater flexibility or certainty does not only affect the NGA investment level, but also the access price. Like Nitsche and Wiethaus (2010) we assume that the incumbent is allowed to recoup investment costs through the access price and it will consider this link when determining investments. In particular we adopt the approach of Sarmento and Brandão (2007) that the regulator sets an access price $w$ equal to the marginal cost of providing the access plus the average cost of the investment. In addition, we incorporate a risk premium into this access pricing formula that takes account of the regulatory uncertainty. A higher (respectively, lower) *m* implies a lower (respectively, higher) regulatory uncertainty. Since the risk premium should compensate the incumbent for the regulatory risk, the regulator has to set a risk premium positively correlated with the regulatory uncertainty. Thus, the proposed risk premium is given by $w_R=(n/m)w$, where $w$ represents the access pricing formula proposed by Sarmento and Brandão (2007).

According to OPTA (2010) "*from the perspective of an investor, uncertainty is only reduced (and hence certainty is provides) when the regulators discloses intended regulatory intervention before the investment is made*". Therefore, we consider the following timing of the game:

- Firstly, the regulator discloses intended regulatory intervention.

- Secondly, the incumbent decides the investment level *X* that maximizes its profits.
- Finally, the retail price and outputs of the firms are defined by Cournot competition between downstream firms.

The backward induction technique is used to find the equilibrium of the whole game. Hence, the analysis begins with the computation of the retail price and the outputs of the firms. Then, using these results, the incumbent's optimal investment level is obtained. Finally, based on the previous information, the optimal regulatory intervention is derived. In particular, we discriminate between two cases according to the range of the intended regulatory intervention. In the first case (section 3), we assume that the regulator sets the optimal regulatory period and then announces the access pricing formula, whereas in the second case (section 4), we assume that the access pricing formula is of common knowledge and hence the intended regulatory intervention only concerns the regulation of the regulatory period. The derivation of all explicit and implicit formulas is available from the authors upon request.

## 3. Case A - Maximum regulatory intervention

In this section, we assume maximum regulatory intervention which implies that the regulator initially sets the regulatory period and then chooses the access pricing formula. Based on this assumption, this section examines the impact of the regulatory period on NGA investment level, competition level and social welfare. Last, it discusses the obtained results from industrial, social and regulatory perspective.

### *3.1. Retail competition outcomes*

According to the model described in section 2, the profits functions of the incumbent and the entrant are given, respectively, by

$$\pi_1 = pq_1 + w_R q_2 - \gamma X_R^2 / 2 \tag{3}$$

$$\pi_2 = (p - w_R) q_2 \tag{4}$$

Considering Cournot competition, the retail price and the output of the firms are the following:

$$q_1 = (A + X_R + w_R)/3 \tag{5}$$

$$q_2 = (A + X_R - 2w_R)/3 \tag{6}$$

$$P = (A + X_R + w_R)/3 \tag{7}$$

### *3.2. NGA investment level*

The incumbent decides the NGA investment level that maximizes its profits. Therefore, substituting Eqs. (5)-(7) into Eq. (3) and taking the first order condition with respect to $X_R$ yields:

$$X_R = \frac{m}{n} X = \frac{2A + 5w_R}{9\gamma - 2} \tag{8}$$

or, in other words,

$$X = \frac{n(2A+5w_R)}{m(9\gamma-2)} \tag{9}$$

From Eq. (8) it is deduced that an increase in the access price leads to an increase in the NGA investment level (ceteris paribus). In addition, note that $\gamma > 0{,}22$ ensures that the incumbent will not choose an infinite investment level.

### *3.3. Regulatory settings*

In this section, we first derive the access pricing formula, as well as, its impact on competition, NGA investment level and social welfare. Based on the derived results, we then compute the optimal length of the regulatory period that maximizes social welfare. Regulatory implications concerning the obtained levels of NGA investment, competition and social welfare are also drawn.

#### *3.3.1. The access pricing formula*

Like Sarmento and Brandao (2007), it is assumed that the regulator sets an access price equal to the marginal cost of providing the access plus the average cost of the investment. Since the marginal cost of providing the access has been normalized to zero, the access price without the incorporation of any risk premium is equal the average cost of the investment, i.e. $w = \gamma X_R / 2$. However, this paper incorporates into the access price a risk premium that takes account of the regulatory uncertainty. Given that $w_R = (n/m)w$ and $X_R = (m/n)X$, the optimal access price that incorporates a risk premium is given by:

$$w_R = \gamma X / 2 \tag{10}$$

Substituting Eq. (9) into Eq. (10) and solving with respect to $w_R$ gives the optimal access price that incorporates a risk premium as a function of the regulatory period *m*:

$$w_R = \frac{2A\gamma n}{18\gamma m - 4m - 5\gamma n} \tag{11}$$

From Eq. (11) it can be concluded that there is a negative correlation between the length of the regulatory period and the optimal access price. Indeed, as the regulatory period increases, the denominator of Eq. (11) also increases as long as $\gamma > 0{,}22$. As a result, the optimal access price decreases with an increase in the regulatory period.

#### *3.3.2. The optimal regulatory period*

In order to assess the impact of an increase in the regulatory period on the NGA investment level, we substitute Eq. (11) into Eq. (8). Hence, we obtain the optimal NGA investment level as a function of the length of the regulatory period[4]:

[4] Superscript “A” characterizes an outcome derived by case A (maximum regulatory intervention), whereas superscript “B” characterizes an outcome derived by case B (minimum regulatory intervention).

$$X_R^A = \frac{4Am}{18\gamma m - 4m - 5\gamma n} \tag{12}$$

Taking the partial derivative of Eq. (12) with respect to *m* gives the change in the optimal NGA investment level caused by a marginal change in the length of the regulatory period:

$$\frac{\partial X_R}{\partial m} = \frac{-20A\gamma n}{(18\gamma m - 4m - 5\gamma n)^2} \tag{13}$$

It is obvious that a marginal increase (respectively, decrease) in the regulatory period leads to a decrease (respectively, increase) in the optimal NGA investment level. This implies that regulatory certainty provides the incumbent with disincentives to invest in NGA networks. The interpretation of this surprising and unexpected result is that a higher regulatory period has a negative effect on the level of the access price, which leads to lower incumbent's profits. This result outweighs the positive effect of a higher regulatory period on the consumers' willingness to pay which positively affects the incumbent's profits. Since the incumbent undertakes the NGA investment level that maximizes its profits, it is reasonable that it will deploy a smaller NGA network as the regulatory period becomes longer.

In addition, substituting Eqs. (8) and (11) into Eqs. (5)-(7) gives the retail price and the output of the firms as a function of the regulatory period:

$$q_1 = \frac{A\gamma(6m-n)}{18\gamma m - 4m - 5\gamma n} \tag{14}$$

$$q_2 = \frac{3A\gamma(2m-n)}{18\gamma m - 4m - 5\gamma n} \tag{15}$$

$$q^A = q_1 + q_2 = \frac{4A\gamma(3m-n)}{18\gamma m - 4m - 5\gamma n} \tag{16}$$

$$P = \frac{A\gamma(6m-n)}{18\gamma m - 4m - 5\gamma n} \tag{17}$$

**Assumption 1.** *Let* $2m - n > 0$*.*

This assumption guarantees that the optimal regulatory period is set at a level that does not foreclose the entrant from the retail (downstream) market. This implies that $\gamma > 0{,}5$ is a necessary condition in order to ensure that the denominator of Eqs. (14)-(17) is positive when $2m - n = 0$. By taking the partial derivatives of Eqs. (14) and (15) with respect to *m,* we can deduce that a marginal increase in the regulatory period causes the incumbent's output to decrease and the entrant's output to increase. Concerning the total output, it can be concluded that it increases with an increase in the regulatory period if $\gamma > 1{,}33$. Since the level of the total output can be used as a measure of the competition level, we can infer that as far as $\gamma > 1{,}33$ the competition level increases with an increase in the regulatory period.

This implies that if $\gamma < 1{,}33$ both the NGA investment level and the competition level decrease with an increase in the regulatory period. As a result, the optimal regulatory policy is to set the regulatory period at its lower feasible level, which is

$m = n/2$. However, such a policy forecloses the entrant from the retail market. Therefore, we make the following assumption:

**Assumption 2.** *Let* $\gamma > 1{,}33$.

This assumption guarantees that there is a trade-off between encouraging investments in NGA networks and promoting competition. In particular, as the regulatory period increases, the competition level increases and the investment level decreases.

We have already studied the impact of the regulatory period on the levels of NGA investment and competition. We have concluded that no regulatory period is capable of achieving the simultaneous maximization of competition and investments. Thus, we study the impact of regulatory period on social welfare since this policy provides intermediate results in terms of NGA investment level and on the subsequent competition level, while is widely used by regulators, policy makers and economists.

Social welfare is the unweighted sum of both providers' profits and consumer surplus. Given that under Cournot competition the consumer surplus is given by $CS = (q^2)/2$, social welfare is:

$$SW^A = \frac{4A^2\gamma(36\gamma m^2 + 3\gamma n^2 - 2m^2 - 21\gamma mn)}{(18\gamma m - 4m - 5\gamma n)^2} \tag{18}$$

Therefore, the partial derivative of Eq (18) with respect to *m* is the following:

$$\frac{\partial SW}{\partial m} = \frac{4A^2\gamma^2 n[m(18\gamma - 64) + 3n(8-\gamma)]}{(18\gamma m - 4m - 5\gamma n)^3} \tag{19}$$

From Eq. (19) we deduce that as the length of the regulatory period increases, social welfare increases until it reaches its maximum level and then decreases. The optimal regulatory period that maximizes social welfare is given by:

$$m = \frac{3n(8-\gamma)}{2(32-9\gamma)} \tag{20}$$

A longer regulatory period than the optimal one has a negative effect on both NGA investment level and social welfare. In addition a shorter regulatory period than the optimal one negatively affects social welfare and positively affects NGA investment level. Therefore, in the last case the regulator has to make a trade-off between the positive effects of greater flexibility on investment incentives and possible negative effects of erroneous intervention on welfare.

Considering this optimal regulatory period, the optimal output of the firms, as well as, the optimal NGA investment level are the following:

$$q_1 = \frac{20A\gamma}{9\gamma^2 + 31\gamma - 24} \tag{21}$$

$$q_2 = \frac{3A\gamma(3\gamma - 4)}{9\gamma^2 + 31\gamma - 24} \tag{22}$$

$$q = \frac{A\gamma(9\gamma + 8)}{9\gamma^2 + 31\gamma - 24} \tag{23}$$

$$X_R = \frac{3A(8-\gamma)}{9\gamma^2 + 31\gamma - 24} \tag{24}$$

**Assumption 3.** *Let* $1{,}33 < \gamma < 3{,}55$.

As noted earlier, the lower bound of this inequality guarantees that the regulatory policy does not foreclose the entrant from the retail market, while it ensures that the denominator of Eqs. (21)-(24) is positive. The upper bound of this inequality guarantees that the length of the optimal regulatory period and the NGA investment level are both positive.

An interesting result obtained by Eq. (20) is that the optimal regulatory period is positively affected by *n* and $\gamma$. Hence, as the NGA investment becomes marginally more expensive, the optimal regulatory period increases. In addition, for relative high values of $\gamma$, the optimal regulatory period increases with a significant increasing rate. Indeed, the derivative of Eq. (20) with respect to $\gamma$ is given by $60n/(9\gamma - 32)^2$. As a result, as $\gamma$ increases, the optimal regulatory period increases with an increasing rate. In particular, it is proven that it is socially optimal for the regulator to provide a greater (respectively, lower) than expected certainty if the rate at which an NGA investment becomes marginally more expensive is higher (respectively, lower) than 2,66.

Concerning the impact of the optimal regulatory period on the total output, it can be deduced that if $\gamma > 2{,}46$, a higher $\gamma$ leads to a higher total output, or in other words, to a higher competition level. On the contrary, if $\gamma < 2{,}46$ a lower $\gamma$ leads to a higher competition level.

Concerning the impact of $\gamma$ on social welfare, it is deduced that as $\gamma$ and *m* increase, social welfare decreases. The same result is obtained by examining the relationship between $\gamma$ and $X_R$. In particular, as the NGA investment becomes marginally more expensive, the regulator sets a longer regulatory period which leads the incumbent to deploy a smaller NGA network. The rationale of this surprising result is that the access price derived by the optimal regulatory policy concerning the regulatory period is negatively affected by an increase in $\gamma$. The reason is that as $\gamma$ increases, *m* increases as well, which implies that the access price decreases. The combination of an increasing marginal investment cost and a high regulatory period leads the incumbent to deploy a smaller network.

### *3.3.3. Discussion*

The study of the impact of regulatory period on investment incentives, competition level and social welfare provides some very significant results concerning the regulatory dilemma between providing greater certainty or greater flexibility. The main conclusion is that there is a trade-off between encouraging investments in NGA networks and fostering efficient competition. Another significant and unexpected result is that greater regulatory certainty leads to lower NGA investment levels and to higher competition levels.

In the following section we discuss the impact of the regulatory period on investment incentives, competition level and social welfare assuming minimum regulatory intervention, which implies that the regulator only sets the regulatory period since the access pricing formula is of common knowledge. The comparison of the results of the two approaches (maximum and minimum regulatory intervention) will disclose the impact of the uncertainty incurred due to the ambiguity for the access pricing formula, which is not usually compensated by the regulators, on the levels of NGA investments, competition and social welfare.

## 4. Case B - Minimum regulatory intervention

This section examines the impact of the regulatory period on NGA investment level, competition level and social welfare assuming minimum regulatory intervention. This implies that the access pricing formula is of common knowledge and hence the profits functions of the incumbent and the entrant are given, respectively, by:

$$\pi_1 = pq_1 + (\gamma X q_2 - \gamma X_R^2)/2 \tag{25}$$

$$\pi_2 = (p - \gamma X/2)q_2 \tag{26}$$

Equations (25) and (26) have been derived by substituting Eq. (10) in Eqs. (3) and (4), respectively.

### *4.1. Retail competition outcomes*

Considering Cournot competition, the retail price and the output of the firms are the following:

$$q_1 = (A + X_R + \gamma X/2)/3 \tag{27}$$

$$q_2 = (A + X_R - \gamma X)/3 \tag{28}$$

$$P = (A + X_R + \gamma X/2)/3 \tag{29}$$

### *4.2. NGA investment level*

The incumbent decides the NGA investment level that maximizes its profits. Therefore, substituting Eqs. (27)-(29) into Eq. (25) and taking the first order condition with respect to $X$ yields:

$$X = \frac{5A\gamma n^2 + 4Amn}{5A\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2} \tag{30}$$

Therefore,

$$X_R^B = \frac{m}{n} X = \frac{m}{n}\left[\frac{5A\gamma n^2 + 4Amn}{5A\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2}\right] \tag{31}$$

By taking the first derivative of Eq. (31) with respect to *m*, it can be deduced that $X_R$ is a concave function of *m*. In particular, as *m* increases, $X_R$ increases until it reaches its maximum level and then decreases. The maximum level of the NGA investment is given by[5]:

$$m_{X_R} = [4\gamma n + 3\gamma n\sqrt{2(5\gamma + 2)}]/(18\gamma + 4) \tag{32}$$

[5] The second root of the first derivate of Eq. (31) with respect to *m* is rejected since it leads to a negative regulatory period.

Taking the first derivative of Eq. (32) with respect to $\gamma$ shows that as $\gamma$ increases, $m_{X_R}$ increases too. This implies that as the cost of the investment becomes marginally more expensive, the regulator provides greater regulatory certainty in order to maximize investments by the incumbent.

### *4.3. Regulatory settings*

We have already mentioned above that the regulator's goal is not only to maximize investments, but also to maximize competition. Therefore, we also discuss the impact of the regulatory period in total output (and hence on consumer surplus). Substituting Eq. (31) into Eqs. (27) and (28) gives the output of the incumbent and the entrant, respectively, as a function of *m*:

$$q_1 = \frac{A\gamma(12m^2 - 2mn + 5\gamma n^2)}{2(5\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2)} \tag{33}$$

$$q_2 = \frac{3A\gamma m(2m-n)}{5\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2} \tag{34}$$

Therefore, the total output is given by:

$$q^B = \frac{A\gamma(24m^2 - 8mn + 5\gamma n^2)}{2(5\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2)} \tag{35}$$

By taking the first derivative of Eq. (35) with respect to *m,* it can be deduced that $q$ is a concave function of *m*. In particular, as *m* increases, $q$ increases until it reaches its maximum level and then decreases. The maximum level of the total output is given by[6]:

$$m_q = [15\gamma^2 n + 10\gamma n + 3\gamma n\sqrt{5(5\gamma^2 + 12\gamma + 4)}]/(48\gamma + 16) \tag{36}$$

Taking the first derivative of Eq. (36) with respect to $\gamma$ shows that as $\gamma$ increases, $m_q$ increases too. This implies that as the cost of the investment becomes marginally more expensive, the regulator provides greater regulatory certainty in order to maximize the competition level.

The comparison of $m_q$ and $m_{X_R}$ shows that $m_q > m_{X_R}$ for all admissible values of $\gamma$.[7] This implies that the minimum regulatory period that the regulator should set is $m_{X_R}$ and the maximum is $m_q$. The rationale of this implication is that as long as $m < m_{X_R}$[8], an increase in *m* causes both levels of NGA investment and competition to increase, whereas when $m > m_q$, a further increase in *m* causes both levels of NGA investment and competition to decrease. Another very significant result is that there is a trade-off between encouraging investments and

---

[6] The second root of the first derivate of Eq. (35) with respect to *m* is rejected since it leads to a negative regulatory period.

[7] $\gamma > 0{,}5$ is sufficient to ensure that the denominator of Eqs. (30) and (33)-(35) is positive when *m* reaches its minimum level, that is $m = n/2$. However, we assume that $1{,}33 < \gamma < 3{,}55$ in order to make the results of sections 3 and 4 comparable.

[8] It is proven that $m_{X_R} > n/2$ for $\gamma > 0{,}5$ and hence the regulator can set $m \in (\frac{n}{2}, m_{X_R})$.

promoting competition as long as $m_{X_R} < m < m_q$. In this case, an increase in the regulatory period causes the NGA investment level to decrease and the competition level to increase. Therefore, we conclude that the regulator cannot achieve the maximization of both investments and competition unless it sets the regulatory period at the level that forecloses the entrant, i.e. $m = n/2$, since in this case $m_q = m_{X_R}$.

In addition, it is found that the regulatory period that maximizes competition is higher than the expected period as long as assumption 3 holds, whereas the regulatory period that maximizes investments is higher than the expected one as long as $\gamma > 2{,}341$. This implies that for relative high values of $\gamma$, the optimal regulatory policy is to set *m* at a higher level than the expected one since the minimum level of regulatory period is $m_{X_R}$.

However, $m_q$ and $m_{X_R}$ are extremely biased towards either competition or investments, respectively. Thus, we discuss the impact of regulatory period on social welfare which provides intermediate outcomes and can be used as a measure of comparison of the results obtained by different regulatory approaches. Social welfare is given by:

$$SW^B = \frac{A^2\gamma(75\gamma^3 n^4 + 500\gamma^2 m^2 n^2 - 180\gamma^2 n^3 m + 1152\gamma m^4 - 832\gamma n m^3 + 96\gamma m^2 n^2 - 64 m^4)}{8(5\gamma^2 n^2 + 18\gamma m^2 - 10\gamma mn - 4m^2)^2} \tag{37}$$

It is obvious that it is not possible to derive closed-form solutions for the optimal values of *m* that maximize social welfare due to the high complexity. Thus, we use numerical simulations in order to derive the optimal regulatory period that maximizes social welfare, as well as, the subsequent levels of NGA investment and competition.

The following table shows the regulatory period that maximizes: (i) the NGA investment level; (ii) the competition level (total output); and (iii) social welfare, for different values of $\gamma$ $(1{,}33 < \gamma < 3{,}55)$. It also shows the subsequent levels of NGA investment and competition derived by the regulatory policy that maximizes social welfare.[9]

**Table 1** The effect of $\gamma$ on the optimal regulatory period and on the subsequent outcomes (minimum regulatory intervention)

| $\gamma$ | $m_{X_R}$ | $m_q$ | $m_{sw}$ | $X_R^{SW}$ | $q^{SW}$ | $SW$ |
|---|---|---|---|---|---|---|
| 1,4 | 3,2 | 4,58 | 4,32 | 31,47 | 47,52 | 2049 |
| 1,8 | 3,57 | 5,65 | 5,28 | 22,46 | 43,21 | 1743 |
| 2,2 | 3,89 | 6,69 | 6,24 | 17,56 | 40,91 | 1588 |
| 2,6 | 4,18 | 7,73 | 7,20 | 14,45 | 39,49 | 1494 |
| 3,0 | 4,44 | 8,76 | 8,17 | 12,29 | 38,52 | 1431 |
| 3,4 | 4,69 | 9,78 | 9,15 | 10,70 | 37,81 | 1385 |

[9] The assumed parameters are $A = 50$ and $n = 4$. These values are used in every numerical example presented in this paper in order to make the results comparable.

A number of observations derived by the analysis of Table 1 are instructive. First, the above table confirms that an increase in $\gamma$ causes both $m_q$ and $m_{X_R}$ to increase. Second, it can be concluded that as $\gamma$ increases, the optimal regulatory period that maximizes social welfare ($m_{sw}$)increases too. This implies that regardless of the particular value of $\gamma$, social welfare increases with an increase in *m* until it reaches its maximum level and then decreases. Not surprisingly, although $m_{X_R} < m_{sw} < m_q$, the regulatory period that maximizes social welfare is biased towards consumer surplus. Last, the subsequent levels of NGA investments ($X_R^{SW}$), total output ($q^{SW}$) and social welfare ($SW$) resulted by the regulatory policy that maximizes social welfare, decrease with an increase in $\gamma$.

In the following section, we compare the results obtained by the two approaches (maximum and minimum regulatory intervention) in order to assess the impact of the ambiguity for the access pricing formula on NGA investments, competition and social welfare.

## 5. Comparison of the two regulatory approaches

Initially, we examine the impact of the ambiguity for the access pricing formula on the incumbent's incentives to invest in NGA networks. Therefore, the comparison of Eqs. (12) and (31) shows that $X_R^B$ is higher than $X_R^A$ for all admissible values of $\gamma$ and *m*. This implies that the ambiguity for the access pricing formula increases the regulatory uncertainty which negatively affects the incumbent's investment incentives. Figure 1 presents graphically the impact of the regulatory period on NGA investment level for each of the two regulatory approaches studied in this paper.

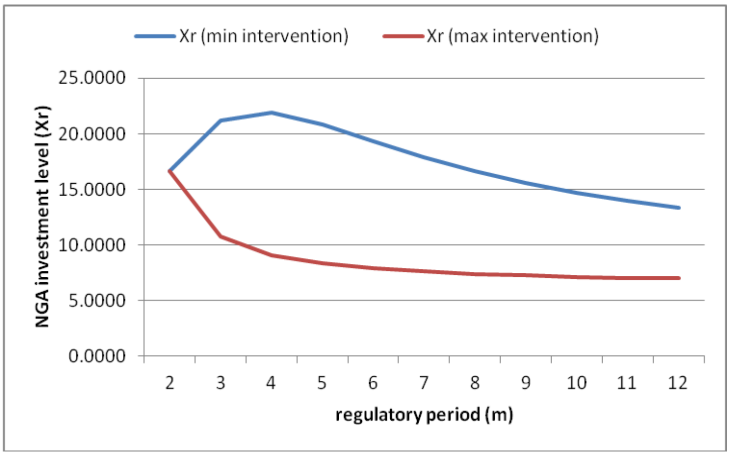


**Figure 1** The impact of the regulatory period on NGA investment level ($\gamma = 2$)

Figure 1 shows that when the access pricing formula is of common knowledge, the NGA investment level is higher that the respective level of NGA investment derived when the regulator discloses the access pricing formula after the announcement of the regulatory period. In addition, the two levels of NGA investment are the same when $m = n/2$, which implies that the regulatory policy forecloses that entrant from the retail market. Not surprisingly, an increase in the regulatory period causes the NGA investment level to decrease under maximum regulatory intervention, whereas under minimum regulatory intervention the NGA investment curve initially increases with an increase in *m*, reaches its maximum level and then decreases.

Concerning, the impact of the ambiguity for the access pricing formula on the total output, the comparison of Eqs. (16) and (35) shows that $q^A = q^B$ for $m_1 = n/2$ and $m_2 = \gamma n/4$. This implies that when $\gamma \leq 2$, $q^B > q^A$. If on the contrary, $\gamma > 2$, $q^B > q^A$ for $m > m_2$ and $q^B < q^A$ for $m_1 < m < m_2$. Figure 2 presents graphically the impact of the regulatory period on total output for each of the two regulatory approaches studied in this paper.

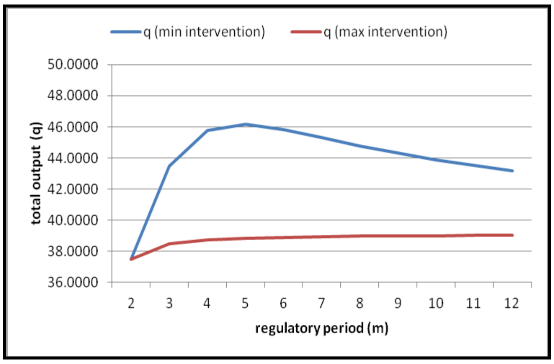


**Figure 2a** The impact of the regulatory period on total output ($\gamma = 1{,}5$)

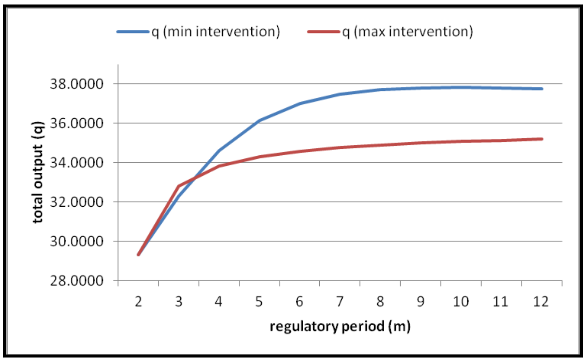


**Figure 2b** The impact of the regulatory period on total output ($\gamma = 3{,}4$)

It is obvious that in the first case of figure 2, the total output derived by minimum regulatory intervention is higher that the respective level of total output derived by maximum regulatory intervention. This implies that the optimal policy for the regulator is to provide a stable regulatory environment in which the access pricing formula would be of common knowledge. On the contrary, when $\gamma > 2$ the regulator should set $m > m_2$ in order to avoid another trade-off between disclosing the access pricing formula after the regulation of the regulatory period (a policy that fosters competition) and providing a stable regulatory environment (a policy that encourages investments in NGA networks).

Last, we discuss the impact of the ambiguity for the access pricing formula on social welfare. The comparison of Eqs. (18) and (37) shows that there is a high complexity for concluding either that $SW^B > SW^A$ or $SW^B < SW^A$. For this reason we use numerical simulations by substituting the values of $\gamma$ used in Table 1 into Eq. (20) in order to calculate the optimal regulatory period under maximum regulatory intervention. Therefore, we focus on the comparison of the levels of social welfare derived by the regulatory policy that aims at maximizing social welfare rather than on the comparison of the levels of social welfare for every admissible value of *m* and $\gamma$.The obtained results are presented in Table 2.

**Table 2** The effect of $\gamma$ on the optimal regulatory period and on the subsequent outcomes (maximum regulatory intervention)

| $\gamma$ | $m_{sw}$ | $X_R^{SW}$ | $q^{SW}$ | $SW$ |
|---|---|---|---|---|
| 1,4 | 2,04 | 26,72 | 38,93 | 1729 |
| 1,8 | 2,35 | 15,25 | 35,72 | 1483 |
| 2,2 | 2,85 | 9,91 | 34,84 | 1372 |
| 2,6 | 3,76 | 6,89 | 34,75 | 1311 |
| 3,0 | 6,00 | 5,00 | 35,00 | 1275 |
| 3,4 | 19,71 | 3,72 | 35,38 | 1251 |

From Table 2 it is deduced that as $\gamma$ increases the optimal regulatory period that maximizes social welfare ($m_{sw}$) increases, whereas the subsequent levels of NGA investments ($X_R^{SW}$) and social welfare ($SW$) decrease. Concerning the impact of an increase in $\gamma$ on $q^{SW}$, recall from section *3.3.2.* that total output increases with an increase in $\gamma$ as long as $\gamma > 2,46$ and decreases with an increase in $\gamma$ as long as $\gamma < 2,46$.

The comparison of the results presented in Tables 1 and 2 shows that the optimal regulatory period that maximizes social welfare is higher under minimum than maximum regulatory intervention except from very high values of the rate at which the investment cost becomes marginally more expensive. However, the derived results in terms of NGA investment level, total output and social welfare are always higher under minimum regulatory intervention than under maximum regulatory intervention. In other words, the ambiguity for the access pricing formula has a negative effect on NGA investment level, competition level and social welfare as long as the regulator sets the regulatory period at the level that maximizes social welfare.

**Proposition 1**. *As long as the regulator chooses the regulatory policy that maximizes social welfare, it should provide minimum regulatory intervention.*

Proposition 1 states that the regulatory policy that maximizes social welfare is to make the access pricing formula be of common knowledge. Such a policy not only maximizes social welfare but also leads to better results in terms of both NGA investments and competition. However, it is obvious that the final outcome is biased towards competition since $m_{sw}$ is much closer to $m_q$ than to $m_{X_R}$.

## 6. Risk and sensitivity analysis

The main conclusion of the previous section is that the optimal regulatory policy is to provide minimum regulatory intervention. In other words, a stable regulatory environment positively affects both NGA investments and competition. However, the analysis concerning the regulatory policy that provides minimum intervention was based on the assumption that the exact values of $\gamma$ and *n* are known to the incumbent and the regulator. Therefore, it was assumed that the incumbent and the regulator have perfect information about the investment cost and the expected regulatory period. Unfortunately, in fact the exact values of $\gamma$ and *n* are not of common knowledge and hence the regulator, as well as, industry firms make their optimal decision under uncertainty.

This section provides a risk analysis in order to assess the impact of the uncertainty for the exact values of $\gamma$ and *n* on the optimal levels of regulatory periods that maximize NGA investments and total output as described in Eqs. (32) and (36). This section also conducts a sensitivity analysis in order to evaluate the significance of $\gamma$ and *n* on the aforementioned levels of regulatory periods. The results obtained by the risk analysis are presented in Figure 3, whereas the results obtained by the sensitivity analysis are presented in Figure 4.[10]

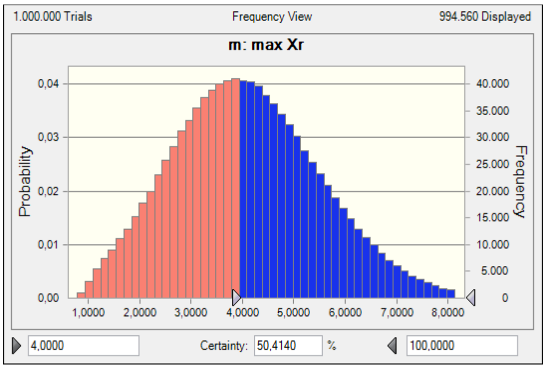


**Figure 3a** The results of risk analysis on $m_{X_R}$

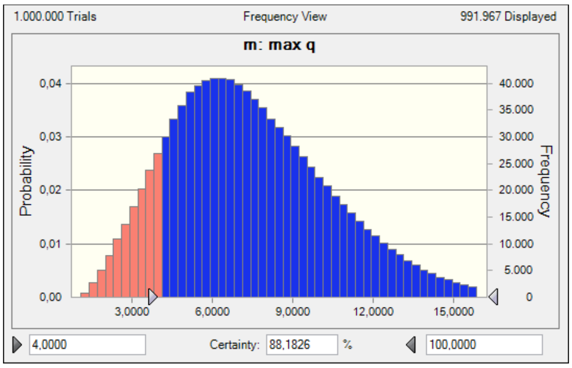


**Figure 3b** The results of risk analysis on $m_q$

Figure 3a shows that the probability of setting the regulatory period that maximizes NGA investments at a higher level than the mean value of the expected one (i.e. *n*=4) is almost 50%. On the contrary, Figure 3b shows that the regulator is expected to set the regulatory period that maximizes competition at a higher level than the mean value of the expected one.

Sensitivity analysis helps us to interpret the results of risk analysis. In particular, Figure 4 shows the impact of each uncertain parameter ($\gamma$ and *n*) on the optimal levels of regulatory periods that maximize NGA investments and total output. It is obvious that *n* rather than $\gamma$ has a more significant impact on $m_q$ and $m_{X_R}$. In addition, a marginal change in *n* causes almost the same deviation in $m_q$ and $m_{X_R}$. On the contrary, although the effect of $\gamma$ on $m_q$ and $m_{X_R}$ is lower than the respective impact of *n* on $m_q$ and $m_{X_R}$, a marginal change in $\gamma$ has a greater impact on $m_q$ rather than on $m_{X_R}$.

[10] We have assigned a uniform distribution to the uncertain parameter $\gamma$ and a normal distribution to the uncertain parameter *n* (mean value: 4; standard deviation: 1,4).

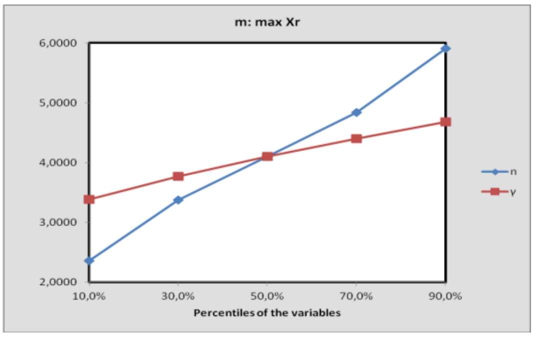


**Figure 4a** The results of sensitivity analysis on $m_{X_R}$

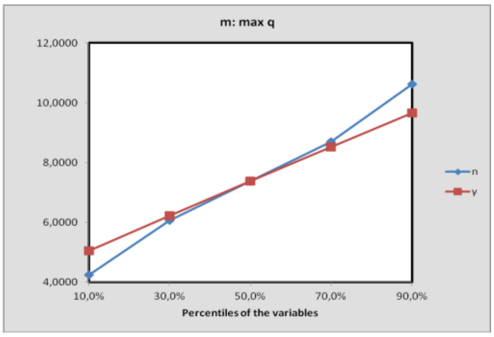


**Figure 4b** The results of sensitivity analysis on $m_q$

Since we have already proved that $m_{sw}$ is much closer to $m_q$ than to $m_{X_R}$, it is expected that the overall uncertainty will have a significant impact on the optimal regulatory period that maximizes social welfare.

## 7. Conclusions

The aim of this paper was to examine the impact of regulatory uncertainty on an incumbent's incentives to invest in NGA networks and on the subsequent downstream competition level. Thus, it proposed a method for calculating the risk premium which compensates the investor for the regulatory risk it incurs when investing in NGA networks. The proposed method is based on the comparison of the regulated period with the expected one. A longer (respectively, shorter) period than expected leads to a lower (respectively, higher) risk premium. We discriminated between two cases according to whether the regulator discloses the access pricing formula (maximum regulatory intervention) after the regulation of the regulatory period or this formula is of common knowledge (minimum regulatory intervention).

In the former case, a longer regulatory period (greater regulatory certainty), leads the incumbent to deploy a smaller NGA network, which in turn results to a higher competition level. Therefore, there is always a trade-off between encouraging NGA investments and promoting effective competition. The rationale of this surprising and unexpected result concerning the NGA investment level is that a longer regulatory period leads to a lower access price, which in turn leads to a decrease in the incumbent's profits. The impact of a lower access price on the incumbent's profits outweighs the positive impact of higher regulatory certainty on consumers' willingness to pay. Therefore, the incumbent is better off by deploying a smaller NGA network as the regulator provides a longer regulatory period in order to offset the higher marginal investment cost.

In the latter case, an increase in the regulatory period causes the levels of both NGA investment and competition to increase until they reach their maximum levels and then to decrease. It is found that the regulatory period that maximizes competition is always higher than the respective level of regulatory period that maximizes NGA investment. This implies that the former period is the highest period that a regulator should set, whereas the latter period is the lowest period that a regulator should set. However, there is also a trade-off between encouraging investments in NGA networks and promoting effective competition since a marginal increase from the lowest to the highest regulatory period causes the investment level to decrease and the competition level to increase.

The deduction from the two regulatory approaches is that although providing minimum than maximum regulatory intervention leads to more expected results and higher investment level, both approaches fail to tackle the trade-off between encouraging investments and promoting competition. For this reason, we assumed that the regulator sets the optimal regulatory period at the level that maximizes social welfare. The comparison of the results derived by the two approaches showed that the regulator should provide minimum than maximum intervention since this policy leads to better results in terms of NGA investments, competition and social welfare.

However, the conclusions presented in this section were based on the assumption that there is perfect information about the investment cost and the expected regulatory period. In reality, the incumbent and the regulator may not have perfect information about the investment cost and the expected regulatory period. For this reason, we also conducted a risk and a sensitivity analysis in order to evaluate the significance of these uncertain parameters on the optimal regulatory periods that maximize investment, competition and social welfare, as well as, the probability of success of every feasible regulatory period. The main conclusion was that the uncertainty about the expected period has a more significant impact on the optimal regulatory periods than cost uncertainty. In addition, it was found that the regulatory period that maximizes competition is more vulnerable to cost uncertainty than the regulatory period that maximizes investments. Therefore, it is expected that the overall uncertainty will have a significant impact on the optimal regulatory period that maximizes social welfare since this period is biased towards the period that maximizes competition than the respective period that maximizes investments.

## Acknowledgments

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# Access Pricing Under Stackelberg Competition: Results Interpretation and Regulatory Implications

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**Abstract—** This paper discusses the impact of the first-mover advantage on the optimal access price that maximizes social welfare. Thus, it compares the results derived when (a) the incumbent; and (b) the entrant, is the Stackelberg leader in the downstream market. It proves that regardless of which firm is the leader, the optimal regulatory policy is to set the access price to the marginal cost of providing the access (first best) since this policy provides zero profits for both firms. Any deviation from this policy leads either the incumbent or the entrant to make a loss and hence to exit the market.

***Index Terms*—Access pricing, Local loop, Competition, Social welfare**

## I. INTRODUCTION

The deregulation of network industries, such as telecommunications, raises several questions about the conditions of access to incumbent firm's network. Without access price regulation, when the incumbent firm is a monopolist in the provision of an essential input (network access) and also a supplier of final products, there is an obvious danger that this integrated firm will seek to exclude competing final product suppliers by setting high access prices, thereby raising rivals' costs [1], [13]. This strategy is known as price squeeze.

Suppose that a new Internet Service Provider (ISP) wants to enter a market monopolized by an incumbent. In this case, the new ISP (the new entrant) can either lease incumbent's facilities or create its own network in order to supply its services to its consumers. Figure 1 depicts graphically the framework that we are presenting.

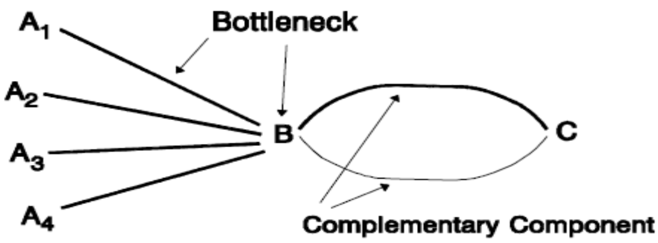


Fig. 1. The framework of access pricing

The monopolist owns all the links between points A1, A2, A3, etc and B that represent the local loop. All of the local consumers A1, A2, A3 , etc must use the monopolist's local loop to communicate with point C, which may be a website or another switch. The same firm that provides access to local loop also provides service from points A1, A2, A3, etc., through switch B to point C.

Therefore, the new entrant can lease the incumbent's backbone facilities between BC (drawn in bold) and the links A1B, A2B, etc. in order to supply its consumers with the "through" service ABC (and CBA). In this case, the new entrant pays an access price for leasing the facilities. Alternatively, the new entrant can invest in its own network. However, that rival owns only facilities between BC since the local loop is still monopolized by incumbent due to its high fixed cost. As a result, the new entrant requires access to (through) the switch in order to provide the A1, A2, A3, etc., customers with the "through" service ABC (and CBA). In this case, each provider pays an interconnection charge for having its traffic terminated on the rival network but the new entrant also pays an access price for having access to the local loop.

The above access issues can be categorized into the two broader categories of access pricing problem: *one-way* access and *two-way* access. One-way access (or the access model) concerns the provision of bottleneck inputs by an incumbent network provider to new entrants, while two-way access (or the interconnection model) concerns reciprocal access between two networks that have to rely upon each other to terminate traffic [16]. In each case, policy makers intervene in the market in order to ensure that access price encourages the right amount of entry, efficient network investment and network utilization, while being manageable. The optimal access price in cases of one-way access has been discussed in [4], [6], [7], whereas the optimal access price in cases of two-way access has been discussed in [8], [9], [11], [12].

Our work is related to the literature on one-way access pricing under Stackelberg competition. Stackelberg model is an oligopoly model in which firms choose quantities sequentially. In our model there are only two firms and as a result it is described by Stackelberg duopoly: a model of duopolies under which two firms choose the quantity to produce with one firm (the leader) choosing before the other (the follower) in an observable manner. Stackelberg competition is widely applied to telecommunication market since:

i. incumbent has already developed network facilities that cover the whole market whereas new entrants invest mainly in profitable areas.

ii. incumbent was the only provider in the market before entry occurs. Therefore, it is reasonable that incumbent will have the largest market share due to the existence of switching costs.

As a result, incumbent supplies its consumers and then provide the unused network facilities to new entrants in order to supply their consumers. For the above reasons, the incumbent is thought to be the Stackelberg leader.

However, Ji-Ho Joo, Hyeon-Mo Ku & Jae-Cheol Kim [6] support that in view of the recent regulatory trend that the incumbent, when requested, is obligated to provide its own bottleneck facilities to entrants, it is more reasonable to take the entrant than the incumbent as the one who plays a leader role. In other words, the incumbent’s decision is dependent on the entrant’s access request, which is taken into account by the entrant in making its decision on facility lease.

Previous works examine a certain instrument of setting the access price under a certain type of competition. In our paper, we examine the effect of each type of Stackelberg competition (when the incumbent is leader and when the new entrant is leader) on the social welfare. Then, we compare the results in order to draw regulatory implications. As a result the regulator has a broader knowledge about the possible outcomes that result from the competition between incumbent and new entrant. Hence, regulator can take the necessary measures in order to maximize social welfare and encourage the right amount of entry based on an elaborate analysis of the possible scenarios.

We have to note that our work also differs from previous works in another point:

Related works focus their attention on telephone services. They suppose that the incumbent supplies services in an upstream (local telephone service) market, while both the incumbent and the new entrant supply services in a downstream (long-distance telephone service) market. In the downstream market, new entrant needs access to upstream networks in order to supply services. Thus, it pays an access price for leasing the facilities. In this case, links A1B, A2B, etc. represent the upstream market whereas BC represents the downstream market. As a result, demand for long-distance services is independent to that of local services. On the contrary, our work focuses on broadband services and especially on charging the access to the local loop. Both incumbent and new entrant supply broadband services, but the new entrant needs access to the local loop, which is monopolized by the incumbent. In this case, there is a unique service (the broadband service) with its own demand.

The sections of the paper will assume the following:

- Each provider has its own network in order to supply internet services in the market. However, the entrant pays an access price α to the incumbent for having access to the local loop, which is monopolized by the incumbent.

- The regulator sets the optimal access price that maximizes social welfare W and then the providers determine their production levels that maximize their profits.
- One unit of the facilities is required to supply one unit of the final product.
- There is no outward parallel shift in demand due to an increase in the level of investment.
- The price of the through service ABC (and CBA) is not subject to direct price regulation.
- Since we focus on the access problem, the interconnections among peers are governed by "bill-and keep" arrangements; that is, they do not pay termination charges to each other [9].
- The final services supplied by the providers are homogeneous.
- We set up a linear model in order to derive intuitive implications of this game.

Our analysis proceeds as follows: In section II, we set up a basic model. In section III, we present the model of Stackelberg competition of an entry game when the incumbent is leader and when the new entrant is leader. In section IV, we analyze the outcomes under each type of competition. In section V, we draw regulatory implications from the interpretation of the results presented in section IV. The final section summarizes the above implications from regulatory point of view.

## II. THE MODEL

*Let* $q_i, q_e$ *be the quantity supplied by the incumbent and the new entrant respectively. The total quantity supplied by the providers is then* $q = q_i + q_e$*. The demand function is given by* $P = P(q)$*. The cost function of the incumbent is* $C_i(q_i, q_e)$*, whereas the cost function of the entrant is* $C_e(q_e)$*. Incumbent's profit is given by*

$$\pi_i = P(q)q_i + aq_e - C_i(q_i, q_e) \tag{1}$$

and new entrant's profit is given by

$$\pi_e = P(q)q_e - aq_e - C_e(q_e) \tag{2}$$

According to the linear model, demand function is

$$P = A - Bq = A - Bq_i - Bq_e \tag{3}$$

where all parameters are strictly positive and cost functions are

$$C_i = c_b q_i + c_a q_i + c_a q_e \tag{4}$$

$$C_e = c_b q_e \tag{5}$$

where $c_b$ is the marginal cost of providing the complementary component and $c_a$ is the marginal cost of the access itself, and all are strictly positive. Note that since we focus on the effect of access price ($a \geq 0$) and the type of competition on the decisions of the providers, we have supposed that the providers have identical marginal cost of providing the complementary component.

We assume that regulator sets the optimal access price that maximizes social welfare W defined as the unweighted sum of profits and consumer surplus.

We then consider two cases according to the type of competition between incumbent and new entrant after knowing the optimal access price. In the first case, the incumbent is Stackelberg leader and the new entrant is Stackelberg follower, while in the second case the new entrant is Stackelberg leader and the incumbent is Stackelberg follower. The Stackelberg leader moves first (decide its optimal capacity/output) and then the follower provider moves sequentially.

## III. COMPETITION BETWEEN THE TWO ISPS

### A. *The incumbent is Stackelberg leader*

Substituting (3) and (4) in (1) gives the incumbent's profit function

$$\pi_i = Aq_i - Bq_i^2 - Bq_i q_e + aq_e - c_b q_i - c_a q_i - c_a q_e \tag{6}$$

The first-order condition is

$$\frac{\partial \pi_i}{\partial q_i} = \frac{A + c_b + a}{2} - Bq_i - c_b - \frac{c_a}{2} - \frac{a}{2} = 0 \tag{7}$$

which gives the level of output ($q_i$) that maximizes profits for the incumbent, the leader.

$$q_i = \frac{A - c_b - c_a}{2B} \tag{8}$$

The incumbent supposes that the entrant will follow its best response and hence subtract it away from the market demand to find its residual demand curve. Using this residual demand curve, the incumbent defines the price $P$.

$$P = \frac{A + 3c_b + c_a + 2\alpha}{4} \tag{9}$$

Total output $q$ is the quantity that gives rise to price $P$ using the market demand curve D.

$$q = \frac{3A - 3c_b - c_a - 2\alpha}{4B} \tag{10}$$

The entrant (the follower) produces the difference between total output ($q$) and the output produced by the leader.

$$q_e = \frac{A - c_b + c_a - 2\alpha}{4B} \tag{11}$$

Substituting (8), (9) and (11) in (1) gives the incumbent's profits $\pi_i$, whereas substituting (8), (9) and (11) in (2) gives the new entrant's profits $\pi_e$.

$$\pi_i = \frac{A^2 - 2Ac_b - 6Ac_a + 6c_a c_b + c_b{}^2 + c_a{}^2 + 4Aa - 4ac_b + 4ac_a - 4a^2}{8B} \tag{12}$$

$$\pi_e = \frac{A^2 - 2Ac_b + 2Ac_a - 2c_a c_b + c_b{}^2 + c_a{}^2 - 4Aa + 4ac_b - 4ac_a + 4a^2}{16B} \tag{13}$$

The function that gives the consumer surplus (CS) for every access price is given by:

$$CS=\frac{9A^2-18Ac_b-6Ac_a+6c_ac_b+9c_b{}^2+c_a{}^2-12Aa+12ac_b+4ac_a+4a^2}{32B} \quad (14)$$

We have already mentioned that social welfare is defined as the unweighted sum of profits and consumer surplus. As a result, social welfare is the sum of (12), (13) and (14). Moreover, the change in social welfare caused by a marginal change in the access price is the sum of the changes in incumbent's profits, new entrant's profits and consumer surplus caused by a marginal change in the access price. The change in social welfare caused by a marginal change in the access price is given by:

$$\frac{\partial W}{\partial a}=\frac{-A+c_b+3c_a-2a}{8B} \quad (15)$$

The first order condition is $\frac{\partial W}{\partial a}=0$ which gives the level of access price that maximizes social welfare.

$$\alpha^*=\frac{-A+c_b+3c_a}{2} \quad (16)$$

Substituting (16) in (8) and (11) gives the optimal capacity decision of incumbent and new entrant respectively.

$$q_i^*=\frac{A-c_b-c_a}{2B} \quad (17)$$

$$q_e^*=\frac{A-c_b-c_a}{2B} \quad (18)$$

The sum of (17) and (18) gives the optimal level of total output which gives rise to the price in the market.

$$q^*=\frac{A-c_b-c_a}{B} \quad (19)$$

$$P^*=c_b+c_a \quad (20)$$

Then, substituting (16) in (12), (13) and (14) gives the incumbent's profits, new entrant's profits and consumer surplus when the access price is set to its optimal level.

$$\pi_i^*=\frac{-A^2+2Ac_b+2Ac_a-2c_ac_b-c_b{}^2-c_a{}^2}{4B} \quad (21)$$

$$\pi_e^*=\frac{A^2-2Ac_b-2Ac_a+2c_ac_b+c_b{}^2+c_a{}^2}{4B} \quad (22)$$

$$CS^*=\frac{A^2-2Ac_b-2Ac_a+2c_ac_b+c_b{}^2+c_a{}^2}{2B} \quad (23)$$

### *B. The new entrant is Stackelberg leader*

Substituting (3) and (5) in (2) gives the new entrant's profit function

$$\pi_e=Aq_e-Bq_e^2-Bq_iq_e-aq_e-c_bq_e \quad (24)$$

The first-order condition is

$$\frac{\partial \pi_e}{\partial q_e} = \frac{A + c_b + c_a}{2} - Bq_e - c_b - a = 0 \qquad (25)$$

which gives the level of output ($q_e$) that maximizes profits for the new entrant, the leader.

$$q_e = \frac{A - c_b + c_a - 2\alpha}{2B} \qquad (26)$$

The new entrant supposes that the incumbent will follow its best response and hence subtract it away from the market demand to find its residual demand curve. Using this residual demand curve, the new entrant defines the price $P$.

$$P = \frac{A + 3c_b + c_a + 2\alpha}{4} \qquad (27)$$

Total output $q$ is the quantity that gives rise to price $P$ using the market demand curve D.

$$q = \frac{3A - 3c_b - c_a - 2\alpha}{4B} \qquad (28)$$

The incumbent (the follower) produces the difference between total output ($q$) and the output produced by the leader.

$$q_i = \frac{A - c_b - 3c_a + 2\alpha}{4B} \qquad (29)$$

Substituting (26), (27) and (29) in (1) gives the incumbent's profits $\pi_i$, whereas substituting (26), (27) and (29) in (2) gives the new entrant's profits $\pi_e$.

$$\pi_i = \frac{A^2 - 2Ac_b - 14Ac_a + 14c_a c_b + c_b{}^2 + c_a{}^2 + 12Aa - 12ac_b + 12ac_a - 12a^2}{16B} \qquad (30)$$

$$\pi_e = \frac{A^2 - 2Ac_b + 2Ac_a - 2c_a c_b + c_b{}^2 + c_a{}^2 - 4Aa + 4ac_b - 4ac_a + 4a^2}{8B} \qquad (31)$$

The function that gives the consumer surplus (CS) for every access price is given by:

$$CS = \frac{9A^2 - 18Ac_b - 6Ac_a + 6c_a c_b + 9c_b{}^2 + c_a{}^2 - 12Aa + 12ac_b + 4ac_a + 4a^2}{32B} \qquad (32)$$

Once again, the level of access price that maximizes social welfare is given by

$$\alpha^* = \frac{-A + c_b + 3c_a}{2} \qquad (33)$$

Substituting (33) in (29) and (26) gives the optimal capacity decision of incumbent and new entrant respectively.

$$q_i^* = 0 \qquad (34)$$

$$q_e^* = \frac{A - c_b - c_a}{B} \qquad (35)$$

The sum of (34) and (35) gives the optimal level of total output which gives rise to the price in the market.

$$q^{*}=\frac{A-c_{b}-c_{a}}{B} \tag{36}$$

$$P^{*}=c_{b}+c_{a} \tag{37}$$

Then, substituting (33) in (30), (31) and (32) gives the incumbent's profits, new entrant's profits and consumer surplus when the access price is set to its optimal level.

$$\pi_{i}^{*}=\frac{-A^{2}+2Ac_{b}+2Ac_{a}-2c_{a}c_{b}-c_{b}{}^{2}-c_{a}{}^{2}}{2B} \tag{38}$$

$$\pi_{e}^{*}=\frac{A^{2}-2Ac_{b}-2Ac_{a}+2c_{a}c_{b}+c_{b}{}^{2}+c_{a}{}^{2}}{2B} \tag{39}$$

$$CS^{*}=\frac{A^{2}-2Ac_{b}-2Ac_{a}+2c_{a}c_{b}+c_{b}{}^{2}+c_{a}{}^{2}}{2B} \tag{40}$$

## IV. RESULTS INTERPRETATION

The analysis of the outcomes $q_{i}^{*}, q_{e}^{*}, q^{*}$, $P^{*}, \pi_{i}^{*}, \pi_{e}^{*}$, $CS^{*}$ and $W^{*}$ that stem from the access price that maximizes social welfare gives us the opportunity to draw the following propositions:

**Proposition 1.** *The type of competition between the providers does not affect the optimal level of the total output, the price of the service, the total profits and the consumer surplus. As a result, it does not affect the social welfare.*

Equations (19) and (36) give the total output when social welfare is maximized under each type of Stackelberg competition. It is obvious that the type of competition does not affect the total output.

Comparing (20) and (37) we infer that the type of competition does not affect the price of the service.

As a result, it is reasonable to assume that the consumer surplus would be the same under each type of competition. Comparing (23) and (40) we conclude that the previous assumption is true.

Last but not least, we note that the total profits are zero under each type of competition.

Since social welfare is the sum of profits and consumer surplus, we infer that the social welfare is the same regardless of the type of competition between the providers. The implication is that the regulator and the consumers are indifferent to the type of competition between the providers.

**Proposition 2.** *The profits of each provider, which stem from the optimal access price, are affected by the difference between the access price and the marginal cost of providing the access.*

We have already proven that under each type of competition the price of the broadband service that maximizes social welfare is given by $P^{*}=c_b+c_a$. As a result, incumbent's profits are also given by $\pi_i^{*}=(a^{*}-c_a)q_e$ and new entrant's profits are also given by $\pi_e^{*}=(c_a-a^{*})q_e$. It is obvious that if incumbent's profits are positive (negative), new entrant's profits are negative (positive), unless both providers' profits are zero.

We have to note that when the optimal access price is equal to zero ($a^{*}=0$) or the optimal access price is negative ($a^{*}<0$), incumbent's profits are negative ($\pi_i^{*}<0$) and new entrant's profits are positive ($\pi_e^{*}>0$). However, when the optimal access price is positive ($a^{*}>0$) we have to discriminate between three cases:

i. The level of the access price is higher than the marginal cost of providing the access, i.e. $a^{*}>c_a$. As a result, $a^{*}-c_a>0 \Rightarrow c_b+c_a>A \Rightarrow P>A$. In this case the price is above the point that the demand curve intersects the price axis and as a result no one consumer is willing to buy the broadband service.

ii. The level of the access price is equal to the marginal cost of providing the access, i.e. $a^{*}=c_a$. As a result, $a^{*}-c_a=0 \Rightarrow c_b+c_a=A \Rightarrow P=A$. In this case the price is equal to the point that the demand curve intersects the price axis and as a result the total quantity is zero. Of course, each provider's output and each provider's profits are zero. Furthermore, consumer surplus and social welfare are zero, too. Once again, no one consumer is willing to buy the broadband service.

iii. The level of the access price is lower than the marginal cost of providing the access, i.e. $a^{*}<c_a$. As a result, $a^{*}-c_a<0 \Rightarrow c_b+c_a<A \Rightarrow P<A$. In this case the price is below the point that the demand curve intersects the price axis and as a result incumbent's profits are negative and new entrant's profits are positive. As we have already mentioned, the total profits are zero. In this case the social welfare is equal to the consumer surplus which is positive. The total output is positive as well. Moreover, when the new entrant is considered as leader, the new entrant serves the whole market, whereas when the incumbent is Stackelberg leader, the two providers have gained the same market share.

**Proposition 3.** *The incumbent's loss is minimized when the optimal access price is positive and the incumbent is Stackelberg leader.*

It is obvious that when $a^{*}>0$, incumbent's loss is lower than when $a^{*}=0$ or $a^{*}<0$. The reason is that when $a^{*}>0$, the difference between the access price and the marginal cost of providing the access is minimized.

However, from (21) and (38) we infer that the incumbent's loss is lower when the incumbent is the Stackelberg leader.

The reason is that when the incumbent is leader, it accepts an additional marginal cost of α/2 in order to continue to produce the same level of output regardless of the level of access price (see equation 8). By accepting this additional marginal cost, the incumbent achieves not only to minimize its loss but also to minimize new entrant's profits. In addition, it achieves to have the same market share with the new entrant, whereas under the other type of Stackelberg competition the incumbent produces nothing.

## V. REGULATORY IMPLICATIONS

The analysis of the above propositions leads to some very significant regulatory implications.

First of all, the regulator is interesting in maximizing the social welfare. However, we have proven that the optimal access price causes the total profits to be zero and the consumer surplus to its maximum level. Since, this level of consumer surplus is the same under each type of Stackelberg competition, we infer that the social welfare is the same under each type of Stackelberg competition, as well. Hence, the regulator is indifferent to the type of competition between the providers, since each type leads to the same level of social welfare. In addition, consumers are also indifferent to the type of competition because the optimal price and the optimal total output are the same under each type of competition.

Secondly, regulator intervenes in the market by setting the access price in order to prevent the incumbent from excluding the new entrant. It is obvious, that regulator aims at encouraging the right amount of entry that, in turn, increases the level of competition and the social welfare. However, from proposition 2 we infer that there are three cases in which the optimal price leads to a positive quantity demanded (there are consumers that are willing to buy the service): i) when $a^*=0$, ii) when $a^*<0$ and iii) when $a^*>0$ and $a^*<c_a$. In all these cases the incumbent's profits are negative and as a result the incumbent exits the market. Hence, the new entrant is only one provider to supply the market. It is reasonable that the monopolist produces its profit maximizing quantity (monopoly quantity). In this case, the total output decreases, price increases and social welfare decreases. In conclusion, the final result is exactly the opposite of the initial aim of regulator. We have to note that this conclusion applies to all types of competition. As a result, the access price that maximizes social welfare fails to achieve an equilibrium point at which consumers are willing to buy the service and both providers' profits are positive.

In conclusion, the *unconstrained* maximization of social welfare is proved to be an inefficient instrument of setting the access price regardless of the type of competition between the providers. As a result, we have explained why regulators do not apply the *unconstrained* maximization of social welfare in order to set the access price that encourages the right amount of entry.

## VI. CONCLUSION

The role of regulator in telecommunication industry is versatile. Among several problems that it has to regulate is the choice of the optimal charge for access to incumbent firm's network and especially to the local loop. The optimal access price should be the result of an elaborate analysis of the market structure, the type of competition, the objectives of regulator, the available instruments of setting the access price and their attributes. Usually, regulator sets the access price that encourages the right amount of entry, efficient network investment and network utilization, while being manageable and increases social welfare.

However, none of the available instruments fulfill all the above objectives. Hence, regulator has to assess the possible outcomes of applying different instruments under different market conditions in order to choose the optimal access price.

In this paper we proved that the access price that maximizes social welfare is the same under each type of Stackelberg competition. This optimal level of access price causes the social welfare to be the same under each type. However, the *unconstrained* maximization of social welfare is an ineffective instrument of setting the access price since it leads the incumbent to have loss and as a result to exit the market. Therefore, the regulator should apply alternative instruments for setting the access price that fulfill its aims.

We have to note that this paper should be regarded as a complement to the existing ones that focus on other types of competition between the providers, such as Cournot and Bertrand competition, and other available instruments, such as the Efficient Component Pricing Rule (ECPR) and retail minus.

The authors already work on modifying the assumption that the providers have identical marginal costs of providing the complementary component. Then, the results will be compared to the results of the application of alternative instruments under different types of competition.

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