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Competition for Access: Spectrum Rights and Downstream Access in Wireless Telecommunications

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Abstract in English

In the market for wireless telecommunications, radio spectrum is an essential input. We study downstream entry and capacity choice in this market, where licenses to use radio spectrum are owned by vertically integrated duopolists. Prior to network construction, these incumbents may offer contracts for capacity to an entrant, granting service-based access on the network they will construct. Alternatively, when spectrum trading is allowed, they may sell part of their license, allowing the entrant to build its own network and enter as an infrastructure player. We find that in this Cournot setting, access is generally provided, as incumbents compete to appropriate the profits of serving a differentiated market through the entrant. Although selling spectrum rights instead of network capacity leads to a loss of economies of scale in infrastructure construction, infrastructure-based entry may dominate as a result of a strategic effect. By delegating capacity choice to the entrant, the access providing incumbent can commit to compete more aggressively, causing its rival incumbent to reduce capacity. A lower aggregate capacity will increase prices and thereby profits.

Keywords: Telecommunications, Vertical Integration, Vertical Foreclosure, Strategic Delegation. JEL classification: L13, L42, L96.

Abstract in Dutch

Radiospectrum is een essentiële input voor draadloze telecommunicatie. We analyseren benedenstroomse toetreding en capaciteitsbeslissingen in een markt waar de licenties om radiospectrum te gebruiken in handen zijn van verticaal geïntegreerde duopolisten. Voorafgaand aan de bouw van hun netwerken kunnen deze gevestigde spelers contracten aanbieden aan een toetreder. Aan de ene kant kunnen ze toegang geven tot hun eigen netwerk. Aan de andere kant kunnen ze een deel van hun spectrumlicentie verkopen aan de toetreder. De toetreder kan dan zijn eigen netwerk bouwen en zo actief worden op de markt. De handel in spectrumlicenties moet dan wel zijn toegestaan. We vinden dat de gevestigde spelers in een Cournotspel altijd toegang verlenen aan de toetreder. Dit komt doordat ze in een gedifferentieerde markt concurreren om de winst van de toetreder. Wanneer een toetreder een eigen netwerk bouwt, worden schaaleffecten niet optimaal benut. Toch kan het voor gevestigde spelers aantrekkelijk zijn om toegang te verlenen tot de eigen infrastructuur vanwege een strategisch effect. Door de capaciteitskeuze aan de toetreder te delegeren, kan de gevestigde speler zich namelijk committeren om minder agressief te concurreren. Hierdoor vermindert diens concurrent ook zijn capaciteit. De lagere totale capaciteit verhoogt de prijzen en daardoor de winst.

Steekwoorden: Telecommunicatie, Verticale Integratie, Verticale Uitsluiting, Strategische Delegatie.

Contents

Summary

Radio spectrum is an essential input for wireless telecommunications such as mobile telephony, wireless internet access or radio broadcasting. Access to this essential resource is restricted to those owning a license. Licenses for using radio spectrum have been introduced in response to a negative externality: too many market participants broadcasting on the same frequency range may cause mutual interference, degrading signal quality. The restriction of access to a limited number of license holders allows these to internalise the externality.

A reduction in the number of players who have access to radio spectrum may also introduce market power in the markets for wireless telecommunications services. Typically relatively few licenses in frequency domains suitable for a particular type of wireless telecommunications are available. License holders will make choices on technology and infrastructure investments, determining the capacity of services they will be able to provide using the patch of radio spectrum allocated to them. Competition in capacity investments between this limited number of license owners may then lead to a suboptimal final capacity level, which allows firms to reap downstream oligopoly rents.

However, oligopoly ownership of upstream spectrum rights does not necessarily imply an oligopoly downstream market. New entrants who do not own a license may contract with the original license holders to use their upstream spectrum rights and provide differentiated services to their customers. We ask whether incumbent license holders will be able to extend their oligopoly ownership of the upstream good – licenses for use of radio spectrum – into a downstream oligopoly of provision of wireless capacity. Will entrants obtain access, and will this entry harm the upstream oligopolists' profits?

In analysing an entrant's opportunities for access, we distinguish between two modes of access: service-based access and infrastructure-based access. First, incumbent spectrum owners may find it worthwhile to offer some capacity on their network to downstream competitors in the wireless telecommunications market, providing service-based access. Secondly, an entrant may buy (or lease) part of the incumbent's spectrum license, and construct its own infrastructure. In this case, the entrant will be able to make independent choices on technology and infrastructure, and on the resulting final capacity it will offer in the downstream market. There is a cost for the incumbent, as it will retain a lower amount of spectrum for its own use, forcing it to invest in more spectrum efficient equipment if it wants to produce similar end-use capacity. Infrastructure-based access relies on the possibility of spectrum trade, where licenses may be sold in whole or in part. Introduction of such spectrum trade is currently a topic of policy discussions.

The aim of this paper is twofold. First, we aim to analyse whether in equilibrium the incumbents who own spectrum licenses will allow entry into the market. Second, we study which type of access occurs in equilibrium. Will an incumbent prefer to offer a contract for

service-based access, reserving capacity on his own network for the entrant, or will he grant access to part of his licensed spectrum, enabling the entrant to build his own infrastructure and make an independent choice of final capacity to offer? Whereas currently service-based access is quite common, facilitating full infrastructure-based access requires further regulatory steps to enable market participants to redefine spectrum rights themselves. From a policy point of view, we ask whether such further regulatory steps could bring additional benefits in spectrum use.

At first sight, the loss of economies of scale in infrastructure-based entry implies that i) aggregate capacity investment under infrastructure based access will be lower than for service-based access, and ii) both entrant and joint profits will be reduced. This would suggest that for incumbents offering service-based access would be a dominant strategy, and that the implementation of spectrum trade would not lead to an increasing number of networks. We argue, however, that commitment properties of both types of access are different. As a result, selling spectrum, rather than access to a network, gives spectrum owners a strategic advantage over rivals, which may offset the loss of economies of scale.

We assume that the spectrum owning incumbents can either offer an entrant capacity on their own networks, or sell part of their spectrum to the entrant. Then, spectrum license holders make capacity choices and compete for end-users. Although we assume there are economies of scale in infrastructure construction which tend to favour service-based access, we find that spectrum sale (and subsequent infrastructure-based entry) may dominate as a result of a strategic effect. Selling spectrum and having the entrant construct its own network allows the incumbent to delegate the capacity choice to the entrant. This acts as a commitment to increase joint incumbent-entrant capacity. Since capacities are strategic substitutes, the rival incumbent is led to decrease output, leaving the access provider and the entrant with higher bilateral profits.

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1 Introduction

Radio spectrum is an essential input for wireless telecommunications such as mobile telephony, wireless internet access or radio broadcasting. Access to this essential resource is restricted to those owning a license. Licenses for using radio spectrum have been introduced in response to a negative externality: too many market participants broadcasting on the same frequency range may cause mutual interference, degrading signal quality. The restriction of access to a limited number of license holders allows these to internalise the externality (see e.g. Faulhaber and Farber, 2002; Cave, 2006b).

A reduction in the number of players who have access to radio spectrum may also introduce market power in the markets for wireless telecommunications services. Typically relatively few licenses in frequency domains suitable for a particular type of wireless telecommunications are available. License holders will make choices on technology and infrastructure investments, determining the capacity of services they will be able to provide using the patch of radio spectrum allocated to them. Competition in capacity investments between this limited number of license owners may then lead to a suboptimal final capacity level, which allows firms to reap downstream oligopoly rents.

However, oligopoly ownership of upstream spectrum rights does not necessarily imply an oligopoly downstream market. New entrants who do not own a license may contract with the original license holders to use their upstream spectrum rights and provide differentiated services to their customers. We ask whether incumbent license holders will be able to extend their oligopoly ownership of the upstream good – licenses for use of radio spectrum – into a downstream oligopoly of provision of wireless capacity. Will entrants obtain access, and will this entry harm the upstream oligopolists' profits?

In analysing an entrant's opportunities for access, we distinguish between two modes of access: service-based access and infrastructure-based access. First, incumbent spectrum owners may find it worthwhile to offer some capacity on their network to downstream competitors in the wireless telecommunications market. An important mode of downstream access in mobile telephony, for instance, is that of Mobile Virtual Network Operators (MVNOs). MVNOs lease wholesale capacity on an incumbent's mobile network and sell services that use this capacity to their retail customers. This form of wholesale access is referred to as service-based access. It has proved popular in the European mobile market: around four mobile telephony network operators are active in each country, but the total number of downstream service providers is substantially higher, up to 60 in the Netherlands and 70 in the UK (European Commission, 2006).

A second mode of access is infrastructure-based access. An entrant may buy (or lease) part of the incumbent's spectrum license, and construct its own infrastructure. In this case, the entrant will be able to make independent choices on technology and infrastructure, and on the resulting final capacity it will offer in the downstream market. There is a cost for the incumbent, as it will retain a lower amount of spectrum for its own use, forcing it to invest in more spectrum efficient equipment if it wants to produce similar end-use capacity.

Infrastructure-based access relies on the possibility of spectrum trade, where licenses may be sold in whole or in part. Historically governments severely restricted the use of licensed spectrum (both regarding type of use and regarding the identity of the user), but current policy aims in many countries include making spectrum licenses more flexible and transferable (see, for the EU, European Commission, 2006; Faulhaber and Farber, 2002, and Cave, 2006b provide an overview of such policy discussions in Europe and the United States). Note that spectrum access is an essential input. An entrant has to enter into a transaction with an incumbent owning spectrum for either network capacity or for spectrum access. This situation differs from entry into fixed-line telecommunications, where infrastructure-based access (constructing one's own network) can typically be achieved independently of the incumbents.

The aim of this paper is twofold. First, we aim to analyse whether in equilibrium the incumbents who own spectrum licenses will allow entry into the market. Second, we study which type of access occurs in equilibrium. Will an incumbent prefer to offer a contract for service-based access, reserving capacity on his own network for the entrant, or will he grant access to part of his licensed spectrum, enabling the entrant to build his own infrastructure and make an independent choice of final capacity to offer? Whereas currently service-based access is quite common, facilitating full infrastructure-based access requires further regulatory steps to enable market participants to redefine spectrum rights themselves. From a policy point of view, we ask whether such further regulatory steps could bring additional benefits in spectrum use.

At first sight, the loss of economies of scale in infrastructure-based entry implies that i) aggregate capacity investment under infrastructure based access will be lower than for service-based access, and ii) both entrant and joint profits will be reduced. This would suggest that for incumbents offering service-based access would be a dominant strategy, and that the implementation of spectrum trade would not lead to an increasing number of networks. We argue, however, that commitment properties of both types of access are different. As a result, selling spectrum, rather than access to a network, gives spectrum owners a strategic advantage over rivals, which may offset the loss of economies of scale.

We focus on a situation where licenses have been allocated, but firms' capacity choices have not been made. We do not study how spectrum rights are initially allocated to the incumbents. In practice spectrum rights are often allocated through beauty contests, or grandfathered to existing incumbents. Increasingly governments also use auctions, but even in that case the number of licenses is usually fixed. Our model may be viewed as analysing the implications of this fixed number of players in the post-allocation market.

The spectrum owning incumbents can either offer an entrant capacity on their own networks, or sell part of their spectrum to the entrant. In the former situation, the incumbent has to construct a network of sufficient capacity to also meet the entrant's contractual requirements for services. In the latter situation, the incumbent will raise his own costs of constructing a network of similar capacity, as it will require more spectrum efficient technology to produce such capacity with a smaller amount of spectrum. After the contracting stage, we assume that the firms engage in differentiated goods Cournot competition. The spectrum scarcity relevant for wireless telecommunications justifies our assumption of competition in quantities, where capacity investment precedes competition in the end user market.

We analyse the access game for the case of an upstream duopoly of spectrum license owners. We allow the two incumbents to propose general non-linear tariffs to the entrant for either capacity on their networks (service-based access) or for access to their spectrum (after which the entrant can construct its own infrastructure).

We find that incumbents will provide entry if the joint profits of the incumbent and the entrant exceed the no-entry duopoly profits. Moreover, since both incumbents compete to provide access in this case, part of the rents of access may be left with the entrant. If incumbents are sufficiently symmetric they face a prisoner's dilemma: both prefer a situation where the entrant stays out of the market, but given that their rival does not provide access, providing access is a best response. In equilibrium, the rents of providing access accrue to the entrant.

Although we assume there are economies of scale in infrastructure construction which tend to favour service-based access, we find that spectrum sale (and subsequent infrastructure based entry) may dominate as a result of a strategic effect. Selling spectrum and having the entrant construct its own network allows the incumbent to delegate the capacity choice to the entrant. This acts as a commitment to increase joint incumbent-entrant capacity. Since capacities are strategic substitutes, the rival incumbent is led to decrease output, leaving the access provider and the entrant with higher bilateral profits.

We study an explicit example with linear demand. There, service-based access occurs when downstream products are strongly differentiated, or economies of scale in infrastructure construction are large. In that case the main contribution to the entrant and incumbent's joint profits is the access to the entrant's differentiated downstream market. Conversely we find that the strategic effect of infrastructure-based access dominates when downstream products are hardly differentiated and economies of scale are not too large. In that case the delegation of the capacity decision to the entrant allows them, jointly, to commit to a larger capacity, leading the rival incumbent to reduce its capacity choice. Incumbent and entrant increase joint profits at the expense of the rival.

This mechanism of increasing joint profits by delegating decision power to the entrant is the reverse of the observation in Salant et al. (1983) that in a homogeneous Cournot market a merger from three to two decreases joint profits of the merging parties: two triopoly profits exceed one duopoly profit. The observation that delegation of decisions to an agent may increase profits has already been observed by Schelling (1960). Caillaud and Rey (1995) provide an overview of some of the subsequent analyses of these ideas. More specifically, the strategic effects of divisionalisation under Cournot competition were analysed in Corchón (1991); Polaski (1992); Baye et al. (1996) and González-Maestre (2000).

The literature on access to upstream bottlenecks for a large part deals with access regulation of vertically integrated monopolists, as reviewed e.g. in Armstrong (2002) and Laffont and Tirole (2000). In this literature, usually capacity constraints are assumed to play no role, the monopolist is required to provide access to its bottleneck against linear tariffs, and monopolist and entrant compete in prices in a horizontally differentiated end user market. This analysis has been particularly relevant to the case of fixed line telephony, where networks were often regarded as natural monopolies. A strand of literature has looked at the benefits of entrants building their own networks, enabling infrastructure competition, and at the demands this places on the system of access regulation (see e.g. Cave, 2006a).

The analysis of competition among upstream oligopolists is still emerging. We are aware of five studies on downstream access in oligopolistic upstream markets in the telecom sector, Ordover and Shaffer (2007), Brito and Pereira (2006), Bourreau et al. (2007), Höffler and Schmidt (2008) and Dewenter and Haucap (2006). These studies ask the question – as we do – on what terms an entrant will be offered access if multiple integrated players compete in the bottleneck sector. The first four papers studies situations where incumbents offer linear tariffs to the entrant, and capacity constraints play no role. They each identify mechanisms that might lead to foreclosure of the entrant. Ordover and Shaffer (2007) and Brito and Pereira (2006) both focus on endogenous product differentiation by the entrant, and the possibility that the entrant cannibalises on the market of its supplier. Bourreau et al. (2007) demonstrate that in equilibrium the access provider's upstream income from access softens its price competition in the downstream market, which is beneficial for its rival incumbent. This may result in a situation where both incumbents prefer their rival to provide entry, and coordination failure may result. Höffler and Schmidt (2008) is related to this analysis, but these authors study a situation where incumbents do not compete to attract entrants. Dewenter and Haucap (2006) consider different types of competition and also note the strategic delegation effect we identify.

Our analysis is related to this strand of literature. In contrast to the existing work, we allow for two different access modes: service-based and infrastructure-based access, to study what type of access incumbents will prefer. Furthermore, we focus on Cournot competition instead of competition in prices as in most papers. Finally, we analyse nonlinear contracts and the impact of contracting externalities, instead of linear price contracts with the entrant. In vertically related markets with both upstream and downstream market power, linear prices give rise to double marginalisation, introducing an inefficiency in addition to the contracting externality that we want to study. Nonlinear contracts eliminate double marginalisation. Our paper is closest to the Cournot analysis by Dewenter and Haucap (2006). Unlike that paper, we focus on the differences in commitment power between the various access modes. Moreover, we model explicitly the contracting game that precedes the competition stage.

Indeed, our paper is related to the literature on vertical contracting, and on vertical foreclosure and exclusive dealing in particular (see e.g. Rey and Tirole, 2007 and Whinston, 2006, chapter 4 for recent overviews). Salinger (1988) considers vertical foreclosure as a result of vertical mergers in bilaterally oligopolistic Cournot markets, under the assumption of linear pricing. Our analysis is more closely related to Hart and Tirole (1990), who demonstrate that even without the inefficiency of linear pricing, vertical mergers may be profitable. The reason may be tracked down to a failure to contract efficiently due to contracting externalities, as also pointed out in Bernheim and Whinston (1998). These authors focus on non-linear contracts for quantities in markets where either the upstream or downstream sector is a monopoly. They analyse equilibrium contracts which may involve exclusivity clauses. We observe that we can adapt their analysis for duopoly upstream providers and a single downstream player, to accommodate the situation where these upstream players are active on the downstream market themselves as well.

The remainder of this article is organised as follows. First we discuss the model and apply it to the simpler situation of a monopoly incumbent to illustrate terminology and mechanisms in a simple setting. Then we turn to the upstream duopoly contracting game and describe the contracting equilibrium in general. Next, we characterise firm profits under service-based access and infrastructure-based access, and analyse the equilibria and the distribution of rents for a particular example. We summarise and conclude in section 5.

2 A benchmark: monopoly incumbent

We start our discussion by introducing the model in a monopoly context. This will serve as a benchmark situation, and allow us to introduce terminology and notation in a simpler framework.

The incumbent

A monopoly mobile operator owns (a license to use) one unit of mobile spectrum, and will use it to offer wireless telecommunications services (say, mobile telephony) to end users. We will refer to the firm as the vertically integrated incumbent, denoted by V. We assume that the unit of radio spectrum (a finite frequency range) controlled by V represents all radio spectrum suitable for mobile telephony. The incumbent V thus controls an essential resource for provision of mobile telecom services (the 'upstream good', i.e., radio spectrum), and may utilise this resource by offering such services to consumers (the 'downstream' market). The costs of supplying a quantity x of mobile telephony services to the market, when owning an amount of spectrum q, are $c(x,q)$. The monopolist, who has one unit of spectrum, $q = 1$, can therefore produce a quantity x of the downstream good at costs $c(x,1)$. We assume that $\partial c_i(x_i,q_i)/\partial x_i > 0$ and $\partial c(x_i,q_i)/\partial q_i \leq 0$. Marginal costs of producing a quantity x are positive, and costs of providing mobile telephony services fall with the frequency range used. For this last condition, one might imagine, for instance, that to supply a quantity x of mobile telephony services to the market, requires a more sophisticated and expensive technology, or a denser antenna network, as the available frequency range shrinks.

Entry

A second party, which we will call the entrant E, would like to provide mobile telephony services y to the market, but E does not own any spectrum itself. The entrant therefore depends on access to V 's spectrum. In principle, entry may occur in two ways. First, the entrant may acquire access to an incumbent's infrastructure. In this way, a mobile virtual network operator (MVNO) is formed. This form of entry is known as service-based access. In this case, both V and the entrant jointly use the same network, and V needs to construct network capacity sufficient to accommodate both its own demand x as well as the capacity contracted by the entrant y. Alternatively, E may enter by buying or leasing spectrum q from V and setting up an independent network. This form of entry is known as infrastructure-based access. Having traded spectrum q both V and E will construct their networks and supply mobile telephony services to the market. V, having kept only $1-q$ units of spectrum, will incur costs $c(x,1-q)$ for producing a quantity x, while E will incur costs $c_E(y,q)$ (which might be equal or similar to $c(x,q)$) . In all cases we assume retail costs to be negligible.

Retail market

We assume both incumbent V and entrant E (if it gains access) compete in quantities in a downstream market with consumers who perceive the two services as horizontally differentiated substitutes. In practice, one may imagine the entrant targeting a specific niche market, selling the service through its proprietary retail channel (E might be a supermarket chain), or offering telephony services bundled with some other product (E may be a bank selling mobile payment services bundled with telephone services). Denoting quantities offered in the final market by x, y, we write V's inverse demand in the retail market as $p(x,y)$, and E's demand as $p_E(x,y)$.

The game

We consider a game in which the incumbent, V, has all the bargaining power. It is modelled as a three stage game, with the following stages. We will analyse this game for both access modes: service-based and infrastructure-based.

1. First, V offers a contract $t(.)$ to E, where the monetary transfer from the entrant to the incumbent, is a (possibly non-linear) function of y, the amount of contracted network capacity (in case of service-based access) or the amount of spectrum q (in case of infrastructure-based access) sold.
2. Next, E may accept or reject the contract. If he accepts V's offer, he chooses a quantity y (or q) and pays $t(y)$ (or $t(q)$) to V.
3. Finally, the incumbent and the entrant sell downstream quantities x and y in the retail market. In case of service-based entry, the incumbent's production costs are $c(x,1)$. In case of infrastructure-based entry, the incumbent's production costs are $c(x, 1-q)$ and the entrant's $c(y,q)$.

We will solve this game by backward induction, and consider subsequently service-based and infrastructure-based access.

Analysis of service-based access

In the case of service-based access, the incumbent will offer a contract $t(y)$ to the entrant, who upon acceptance will choose his quantity y and make the required payment. In the final stage of the game, the incumbent will choose his own quantity x and produce a network capacity $x+y$. Both players will sell their chosen quantities into the market. Excluding transfers, final stage profits for the incumbent are therefore given by

$$\pi(x,y) = p(x,y)x - c(x+y,1)$$

while the entrant's profits will equal

$$\pi_E(x,y) = p_E(x,y)y$$

The monopolist's problem, in the final stage of the game, is to optimise his downstream profits π over capacity x, given accepted quantity y. He solves the first order condition

$$x(y) \in \arg\max_{x} [\pi(x,y)]$$

which we shall assume leads to a unique $x(y)$. Now we turn to the first stages of the game, where the monopolist offers a contract $t(y)$. It is immediate that in this situation the monopolist can choose payment $t(y)$ so as to appropriate the entrant's entire profits, and V therefore will design the contract so as to make E choose a quantity y optimising their joint profits. Since the contract does not specify x this optimisation is subject to $x = x(y)$, the best response to entrant's quantity y. V therefore solves

$$\begin{aligned} &\max_{x,y} [\pi(x,y) + \pi_E(x,y)] \\ \text{s.t. } &x \in \arg\max_{x} [\pi(x,y)] \end{aligned} \tag{2.1}$$

We note here that although V, through the contract it offers, controls E's quantity y, as well as its own x, he cannot in general achieve the profits he would obtain were he integrated with E. The reason is that V faces a commitment problem (as pointed out in Hart and Tirole, 1990): he cannot commit to E to produce an x different from its individual best response to y. Except in cases where products are either completely independent or perfect substitutes, this constraint rules out joint optimal production.

Analysis of infrastructure-based access

We next turn to infrastructure-based access. In this set-up, V, prior to its network investment decision, sells (or leases) a quantity of 'raw' spectrum q(out of its original endowment of one unit of spectrum) to the entrant E. Subsequently, both V and E invest in their networks and technologies to convert their shares of spectrum into marketable telecommunications capacity. The difference with the service-based access model above is therefore that technology choice (or, effectively, the ratio of capacity compared to available spectrum) is decentralised to the entrant. Contracts now take the form $t(q)$. As the original endowment of spectrum was normalised to one, V will have left at its own disposal a quantity of spectrum equal to $1-q$.

Analysis of the optimal contracts case proceeds in a similar way as for service-based access, albeit that the entrant now also incurs costs of infrastructure investment and makes an individual capacity choice. In the third stage of the game, when spectrum fraction q has been determined, incumbent and entrant will decide on what quantities to produce. Again excluding transfers, profit functions, given spectrum sold q, now take the form

$$\begin{aligned} \pi(x,y;q) &= p(x,y)x - c(x,1-q) \\ \pi_E(x,y;q) &= p_E(x,y)y - c(y,q) \end{aligned}$$

Choices will constitute a Cournot equilibrium $(x(q), y(q))$ between the two players, conditional on spectrum traded, q. In the first stage of the game, the monopolist will solve for q such that the resulting Cournot equilibrium will optimise joint profits, and offer this quantity to the entrant (using the transfer to appropriate all profits). The problem V now solves is

$$\begin{aligned} &\max_q [\pi(x,y;q) + \pi_E(x,y;q)] \\ \text{s.t. } & x \in \arg\max_x [\pi(x,y;q)] \\ \text{and } & y \in \arg\max_y [\pi_E(x,y;q)] \end{aligned} \tag{2.2}$$

As in the case of service-based access, V can not attain the joint optimum quantities. Now, in addition, splitting of production implies loss of economies of scale (production costs for the same capacity are higher when two networks have to be set up) so that also productive efficiency is lower.

Choice between access types

In stage 1, V will, finally, make a choice between infrastructure and access-based entry offers, and will choose the one giving the maximum joint payoffs. In appendix B we study a symmetric, linear demand example. In this case, the choice for service-based access always optimises monopolist profits: the cost disadvantages of infrastructure duplication render infrastructure-based access unattractive. This conclusion is not general, however. As a counterexample, envisage a situation where the incumbent's technology is less efficient than the entrant's. One may for example assume that the firms incur additional retail costs for every unit sold to end consumers. If the entrant's retail costs are lower than the incumbent's, surplus maximisation requires the entrant to produce more than the incumbent. For homogeneous goods, in fact, incumbent sales should be zero. Under service-based access, the incumbent cannot commit not to produce, and an inefficient production mix results. Since by selling the license, the incumbent increases his own production costs, infrastructure-based access allows the incumbent to credibly commit to output reduction. For homogeneous goods, selling the entire spectrum ($q = 1$) to the more efficient entrant is optimal.

3 The duopoly contracting game

Armed with the basic insights of the monopoly incumbent model, we now address the situation in which there is a duopoly in the upstream sector. We now have two wireless spectrum owners, V_1 and V_2 , each owning one unit of spectrum, and offering their wireless telecommunications services to end users. Where in the monopoly situation, the entrant E relies on V's network (or resources) and cannot avoid paying its entire profits to V, in the duopoly case E has a choice and might be expected to be able to play out the two incumbents V_i against each other. We shall see that this is true, but with a qualifier: the access quantity that the entrant may obtain can be low (or zero) in equilibrium.

In the duopoly contracting game, we will concentrate on situations where the entrant E contracts capacity with either incumbent V_1 or incumbent V_2, but not with both. This is a natural assumption if there are large fixed transaction costs of doing business with each additional counterparty. If such costs are not present, also equilibria where both incumbents give access may exist. Moreover, equilibria with only one access provider may in that case require exclusivity clauses. We consider this, more complex situation in appendix C.1.

For analysing the contracting game, we use similar reasoning as Bernheim and Whinston (1998), who analysed a market structure with two rival upstream manufacturers, who offer non-linear contracts to a retailer to sell their goods in the retailer's shop. Here we slightly adapt their analysis to allow for vertical integration of the upstream firms: the incumbents are also active on the downstream market themselves. This implies that, in contrast with the case of purely upstream active manufacturers, also the firm that does not write a contract with the entrant will make non-zero profits (from its own downstream activities), providing it with a valuable outside option.

We model the situation analogously to the incumbent monopoly case discussed above. The entrant will now get an offer $t_i(y_i)$ (or $t_i(q_i)$ in case of infrastructure access) from both V_1 and V_2, (possibly with exclusivity clauses attached) and may choose to accept either offer or reject both. In the final stage, denote V_i 's capacity by x_i, and E 's capacity by y. The three firms V_i and E face an end-user market with inverse demands $p_1(x_1,x_2,y)$, $p_2(x_1,x_2,y)$, $p_E(x_1,x_2,y)$.

We first observe that, like in the monopoly situation, the incumbents will offer contracts to the entrant in which quantities y_i (or q_i) will be such that joint profits of the entrant and incumbent are optimised. (If this were not the case, the incumbent could always profitably deviate to the joint optimal quantity, and use the transfer t_i to appropriate this extra surplus while leaving the entrant indifferent). We define the resulting profits (excluding the transfer t_i) in an equilibrium where V_i is the exclusive access provider as $\pi_1^{(i)}$, $\pi_2^{(i)}$ and $\pi_E^{(i)}$, and furthermore denote joint entrant-incumbent profits by

$$\Pi^{(i)} = \pi_i^{(i)} + \pi_E^{(i)}$$

The question now is, given profits $\pi_{j,E}^{(i)}$, what price t_j both incumbents will offer to the entrant, and who will provide the winning bid. The result, the proof of which is detailed in appendix A, is

Claim 1. *If bilateral profit $\Pi^{(i)} = \pi_i^{(i)} + \pi_E^{(i)}$ of the entrant and incumbent V_i is larger under access than V_i's profits without access, the entrant will be granted access. If access takes place, it will be provided by the incumbent V_i for which total industry profits $\pi_1^{(i)} + \pi_2^{(i)} + \pi_E^{(i)}$ is highest. Equilibrium payoffs (after transfers) are*

$$\begin{array}{rc} E: & \Pi^{(j)} - \pi_j^{(i)} \\ V_i: & \Pi^{(i)} - \Pi^{(j)} + \pi_j^{(i)} \\ V_j: & \pi_j^{(i)} \end{array}$$

The intuition for this result is that, as long as there is a gain to providing access, the incumbents will compete to become the exclusive access provider, leaving some of the rents to the entrant. The winning offer (by V_i) should leave the rival V_j indifferent between winning and losing the contracting game. The share of bilateral rents $\Pi^{(j)}$ that V_j would be willing to leave to the entrant is determined by V_j 's outside option, i.e. earning $\pi_j^{(i)}$ if he does not supply. The proof is an adaptation from the one presented in Bernheim and Whinston (1998).

4 Modes of access

The previous section derived the sharing of profits between entrant and incumbent, given equilibrium profits. Now we analyse the choice of optimal y, q for the service-based and infrastructure-based offers, extending the monopoly analysis carried out above.

A crucial difference with the monopoly situation is that in the final stage, both V_1 and V_2 compete in quantities, given y or q. Where in the monopoly case, V could obviously condition his choice of capacity x on this contracted quantity, the matter is less straightforward in duopoly. While the access provider V_i can certainly take into account y_i when deciding on his own capacity x_i the matter is less obvious for the rival V_j: is the information on y_i (or q_i) available to the non-access-provider at the moment it makes its capacity choice x_j? Clearly the answer to this question influences capacity choices, with the non-access providing rival (say V_2) anticipating a joint best response by V_1 and E, in case of non-observability.

We assume that observability of contracts (or, in a more general model setting, the disability to renegotiate a contract) differs between the two access modes. We would argue that a bilateral contract for access to an incumbent's network (service-based access) is less likely to be observable to the rival incumbent (or more likely to be open for (secret) renegotiation during the investment stage), than a sale of spectrum, and subsequent building activity by the entrant itself (infrastructure-based access). Apart from observable separate building activity, also regulatory arrangements are likely to make spectrum sale more transparent than capacity sales: much like land registry, spectrum allocations (and changes in it) will be publicly registered.

Public observability of contracts leads to a precommitment effect (as studied in Fershtman et al., 1991). The effective delegation of quantity setting decisions that occurs under infrastructure-based competition will influence subsequent competition and therefore market outcomes. We will see that the implications of such strategic delegation in this case may provide a rationale for the access provider to choose for (perhaps productively inefficient) infrastructure-based access, rather than service-based access.

4.1 Service-based access

Under service based competition, we assume that contract quantity y_i is not known to V_j $(i \neq j)$ prior to its capacity investment choice (or can be secretly renegotiated before V_j's investment decision). In a Nash equilibrium, non-access winning player V_j will therefore necessarily assume that the $V_i - E$ couple contracts on an x_i, y_i pair that is an optimal response (in terms of the bilateral profits of V_i and E) to its own capacity choice x_j, and vice versa. Joint profit maximisation again occurs since V_i may use the transfer t_i to redistribute wealth. As in the monopoly benchmark, however, access provider V_i is not free to adjust his own and the entrant's capacities at will: he is constrained by his inability to commit to produce any x_i but the best response to contracted y_i and V_j's anticipated x_j. If in equilibrium V_i makes the winning bid for access to E, the resulting capacity choices will be such that E 's capacity y_i optimises joint profits, but subject to the Nash equilibrium conditions that both x_i and x_j are best responses to both each other and y_i.

Assuming for concreteness that V_1 is the access-provider, we may define the profits (leaving out transfers) in the retail market $\pi_{1,2}$ and π_E of the incumbents and the entrant as

$$\pi_1(x_1,x_2,y_1) = p_1(x_1,x_2,y_1)x_1 - c(x_1+y_1,1)$$
$$\pi_2(x_1,x_2,y_1) = p_2(x_1,x_2,y_1)x_2 - c(x_2,1)$$
$$\pi_E(x_1,x_2,y_1) = p_E(x_1,x_2,y_1)y_1$$

The equilibrium conditions are then given by the following set of equations: V_1 chooses its own sales $x_1^{(1)}$, as well as sales to the entrant $y_1^{(1)}$, to satisfy

$$x_1^{(1)},y_1^{(1)} \in \arg\max_{x_1,y_1} \left[\pi_1(x_1,x_2^{(1)},y_1) + \pi_E(x_1,x_2^{(1)},y_1)\right]$$

subject to the constraint that V_1 acts opportunistically: it chooses $x_1^{(1)}$ optimally given that it sold $y_1^{(1)}$ to the entrant

$$x_1^{(1)} \in \arg\max_{x_1} \left[\pi_1(x_1,x_2^{(1)},y_1^{(1)})\right]$$

V_2 conversely chooses its own sales $x_2^{(1)}$ according to

$$x_2^{(1)} \in \arg\max_{x_2} \left[\pi_2(x_1^{(1)},x_2,y_1^{(1)})\right]$$

Similarly, if V_2 is the (exclusive) supplier, quantities sold would be $x_1^{(2)},x_2^{(2)},y_2^{(2)}$.

4.2 Infrastructure-based access

We next turn to infrastructure-based access, again restricting attention to exclusive contracts. In this set-up, as before in the monopoly benchmark, either incumbent V_1 or V_2 may sell part of their unit endowments of spectrum to the entrant, after which all three players make their individual investment decisions. As above, we use the variable q_i to denote spectrum sold by V_i to the entrant E. Contracts take the form $(t_i(q_i), q_i)$. As original endowments of spectrum to the incumbents were normalised to one, $q_{1,2}$ are the fractions of spectrum that $V_{1,2}$ sell to E. This means that incumbents will have left at their own disposal a quantity of spectrum equal to $1-q_{1,2}$.

As argued, in contrast with the service-based access case where one incumbent controls both its own and the entrant's investment, in this case it is more natural that E and access provider V_i cannot secretly renegotiate their spectrum sale q once the resource has been divested. Rival V_j may credibly observe q_i and base its own capacity choice on this information.

With the information structure as just outlined, in contrast with service-based access, the final capacity stage of the game can be analysed contingent on spectrum sale q_i which now is common knowledge. The analysis resembles the monopoly analysis. The difference is that now three players (instead of two) are involved in the Cournot game, with spectrum input q_i (the entrant), $1-q_i$ (the access provider) and 1 (the rival incumbent). In the third stage of the game, when spectrum fraction q_i has been determined (and is publicly observed), both incumbents and the entrant will decide on what quantities to produce. Taking V_1 to be the exclusive access provider we now have final stage profits (denoting the entrant's capacity by x_E to distinguish from the service-based access game)

$$\begin{aligned}
\pi_1(x_1,x_2,x_E;q_1) &= p_1(x_1,x_2,x_E)x_1 - c(x_1,1-q_1) \\
\pi_2(x_1,x_2,x_E;q_1) &= p_2(x_1,x_2,x_E)x_2 - c(x_2,1) \\
\pi_E(x_1,x_2,x_E;q_1) &= p_E(x_1,x_2,x_E)x_E - c(x_E,q_1)
\end{aligned}$$

The equilibrium quantities in this case are simply the Cournot quantities for the (q_1-dependent) cost structure, satisfying

$$x_1^{(1)}(q_1) \in \arg\max_{x_1} \left[\pi_1(x_1,x_2^{(1)},x_E^{(1)},q_1)\right]$$

and similarly for $x_2^{(1)}(q_1)$ and $x_E^{(1)}(q_1)$.

In the spectrum sale stage of the game, the equilibrium of the final subgame is anticipated and the amount of spectrum sold will solve

$$q_1^{(1)} \in \arg\max_{q_1} \left[\pi_1(x_1^{(1)},x_2^{(1)},x_E^{(1)},q_1) + \pi_E(x_1^{(1)},x_2^{(1)},x_E^{(1)},q_1)\right] \tag{4.1}$$

4.3 Choice between access types

Having analysed the two options separately, we now explore the choice between offering (exclusive) service-based access and infrastructure-based access. Delegation of investment to the entrant, under infrastructure-based access, leads to loss of economies of scale. In the monopoly situation, we observed that in the symmetric situation, this loss of production economies led to a preference for service-based access. In the current duopoly setting, however, there is a countervailing effect: infrastructure-based access allows the supplier to commit to a quantity (of spectrum) assigned to the entrant. The delegation of the quantity choice for part of the spectrum to a third party results, in this Cournot framework, in a commitment to jointly produce larger capacity in the end-user market. While in a monopoly setting this is undesirable, with the Cournot rival this move succeeds in persuading the rival to reduce his end-market quantity. Although industry profits may end up lower as a result of entry, the share of industry profits going to the access-provider and the entrant increases (at the expense of the non-access-provider).[1]

The two mechanisms thus lead to ambiguous incentives in the choice of access mode. In the following example we will observe how, depending on cost levels, either mode of access may be preferred.

4.4 Example

To clarify these results on exclusive contracts, we discuss a concrete example with linear demand and compare competition under service-based access to competition under infrastructure-based access.

Service-based access

We consider Cournot competition in differentiated goods, with linear and symmetric marginal costs c for both incumbents. We also assume linear demand

$$\begin{aligned} p_1 &= 1 - x_1 - \gamma x_2 - \gamma y \\ p_2 &= 1 - \gamma x_1 - x_2 - \gamma y \\ p_E &= 1 - \gamma x_1 - \gamma x_2 - y \end{aligned}$$

where x_i is the quantity the vertically integrated incumbent V_i supplies to the market, and y is the quantity contracted by the entrant with incumbent V_i. Assume without loss of generality that V_1 is the exclusive supplier.

If V_1 offers the entrant a quantity y, the entrant knows that after it has accepted the contact, V_1 will choose to produce according to its best response $R_1(x_2, y_1) = (1 - c - \gamma(x_2 + y))/2$. This implies that under service based competition firm V_1 will choose to supply equilibrium quantity y^* and V_2 will choose to produce equilibrium quantity x_2^* that solve

$$\begin{aligned} y^* &= \arg\max_y \pi_1(R_1(x_2^*, y), x_2^*, y) + \pi_E(R_1(x_2^*, y), x_2^*, y) \\ x_2^* &= \arg\max_{x_2} \pi_2(R_1(x_2^*, y^*), x_2, y^*) \end{aligned}$$

resulting in

$$\begin{aligned} x_1^* = x_2^* &= \frac{(1-c)\left(4 - 2\gamma - \gamma^2\right)}{\gamma(4-\gamma^2) + 8(1-\gamma^2)} \qquad (4.2) \\ y^* &= \frac{4(1-c)(1-\gamma)}{\gamma(4-\gamma^2) + 8(1-\gamma^2)} \end{aligned}$$

For homogeneous products ($\gamma = 1$) this immediately leads to $y = 0$, as in the monopoly case. The incumbent rivals then trivially produce the Cournot duopoly quantities $x_1 = x_2 = \frac{1-c}{3}$. This

[1] This commitment effect is similar to the one observed by Reynolds et al. (1983) in merger analysis in Cournot markets: since for a homogeneous product, twice the triopoly profits exceed the duopoly profits, merger from triopoly to duopoly is not profitable.

implies that in this situation where contracts are unobservable to the rival incumbent, the entrant will not get access to the market. With homogeneous products, both rivals will foreclose entry in equilibrium. Note that if downstream products are differentiated, the entrant will be allowed on the market, with quantities increasing as products become more differentiated. In the limit that products are independent ($\gamma = 0$) we get $x_1^* = x_2^* = y^* = \frac{(1-c)}{2}$, i.e. each firm produces the monopoly quantity in its respective market.

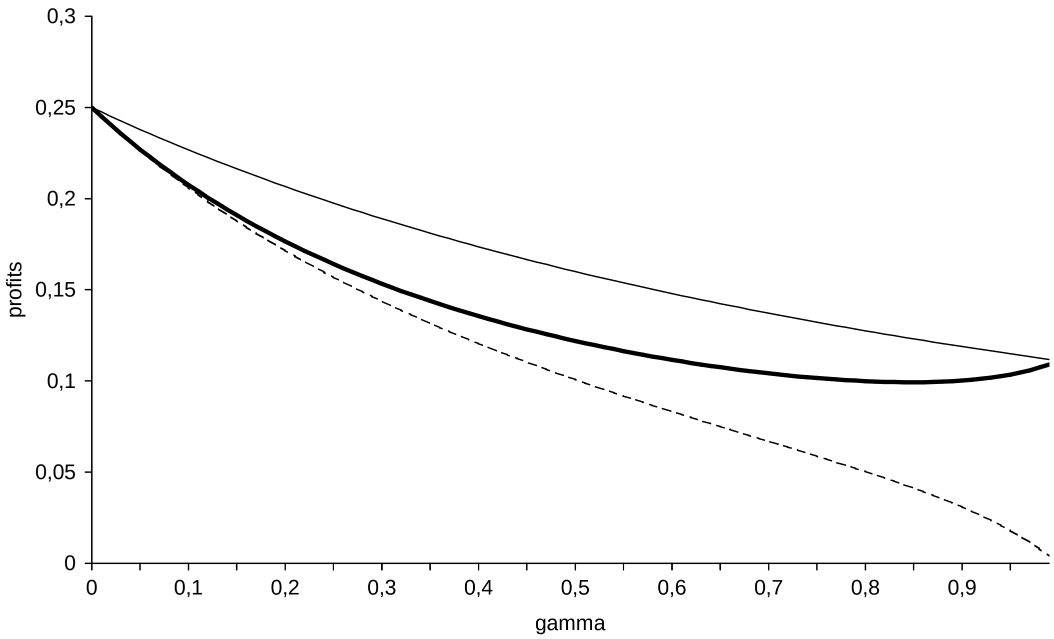
To see who gets what share of the profits in equilibrium, we calculate the firms' profits after transfers using claim 1. We have that in symmetry both incumbents get the excluded incumbent's profit, while the entrant gets the remainder:

$$\Pi_{incumbent} = \Pi_2^{(1)} = (1-c)^2 \frac{\left(\gamma^2 + 2\gamma - 4\right)^2}{\left(\gamma(4-\gamma^2) + 8(1-\gamma^2)\right)^2}$$

$$\Pi_{entrant} = \Pi_{total}^{(1)} - 2\Pi_2^{(1)} = 4\,(1-c)^2 \frac{\left(4 - \gamma^4 + 5\gamma^3 - 4\gamma^2 - 4\gamma\right)}{\left(\gamma(4-\gamma^2) + 8(1-\gamma^2)\right)^2}$$

For $c = 0$, figure 4.1 below shows duopoly profits under exclusion ($\pi = \left(\frac{1-c}{\gamma+2}\right)^2$, without entry, thin line), the incumbent's profits after transfer (thick line) and the entrant's profits after transfer (dashed line). The graph clearly illustrates the effect of competition between the two incumbents to be the entrant's exclusive supplier. Although their profits could increase by not supplying the entrant, in equilibrium the entrant does gain entry (for $\gamma < 1$) and makes nonzero profit. In the absence of an offer by their rival, both incumbents would prefer to supply the entrant and reap the additional rents. However, competition to be the exclusive supplier washes away these rents, and leaves both incumbents worse off.

Figure 4.1 Duopoly profits, compared to incumbents' and entrant's profits under service-based entry



Infrastructure-based access

To analyse infrastructure-based access, we have to assume a dependence of costs on alternative endowments of spectrum resources. A practical description of such a cost structure is that the costs of production only depend on the conversion rate of spectrum q into usable capacity x, or $c(x,q) = c(x/q)$. There are economies of scale: the costs of supplying the market with a quantity $x_1 + x_2$ with spectrum capacity $q_1 + q_2$ by one firm, i.e., $c(x_1 + x_2, q_1 + q_2)$, is lower than costs of providing the same quantity by two networks separately, $c(x_1, q_1) + c(x_2, q_2)$. In practice economies of scale may arise as a result of costs that are only technology dependent (e.g. costs of setting up a network, or of choosing more expensive technology to boost output capacity), rather than output dependent. We continue the example with linear costs, $c(x,q) = cx/q$. Furthermore, we keep the assumption of linear demand with heterogeneous goods: $p_i = 1 - x_i - \gamma x_j - \gamma x_k$ where $i \neq j \neq k \neq i$.

Consider the subgame where V_1 has exclusively sold spectrum $q < 1$ to the entrant, and therefore keeps $1 - q$ for its own use, whereas V_2 owns one unit of spectrum. Marginal production costs of capacity for V_1 are therefore $c/(1-q)$, while V_2 has marginal costs of capacity c and E faces marginal costs c/q. Players then choose what quantity to produce. Effectively, this boils down to Cournot competition with asymmetric costs. The result in terms of profit functions is that

$$\pi_i(c_i, c_j, c_k) = \frac{(2 - \gamma - (2+\gamma)c_i + \gamma c_j + \gamma c_k)^2}{(2\gamma - 2\gamma^2 + 4)^2} \tag{4.3}$$

where $i = 1, 2, E$, and $c_1 = c/(1-q)$, $c_2 = c$ and $c_E = c/q$. Clearly, given the symmetric set-up, analogous results follow for the reverse case where V_2 is the exclusive supplier of spectrum to the entrant. In the contracting stage, the firm providing entry chooses q to optimise bilateral profits $\Pi^{(1)}(q) = \pi_1^{(1)}(q) + \pi_E^{(1)}(q)$. If an interior solution exists, it is necessarily $q = 1/2$ due to the symmetry of bilateral profits with respect to costs c_1 and c_E. For $q = 1/2$ to be a global maximum, profits for $q = 1/2$ should exceed the profit of an individual firm under (symmetric) duopoly. Comparison of the two profits demonstrates that this requires that $c < \frac{2-\gamma}{24\gamma - 6\gamma^2 - \gamma^4 + 56}\left(6\gamma - 2\sqrt{2}\gamma^2 + \gamma^3 - 6\sqrt{2}\gamma - 4\sqrt{2} + 12\right)$. If this condition is not met, the entrant will not gain entry to the market ($q = 0$) under the infrastructure-based access mode.

Choice between access modes

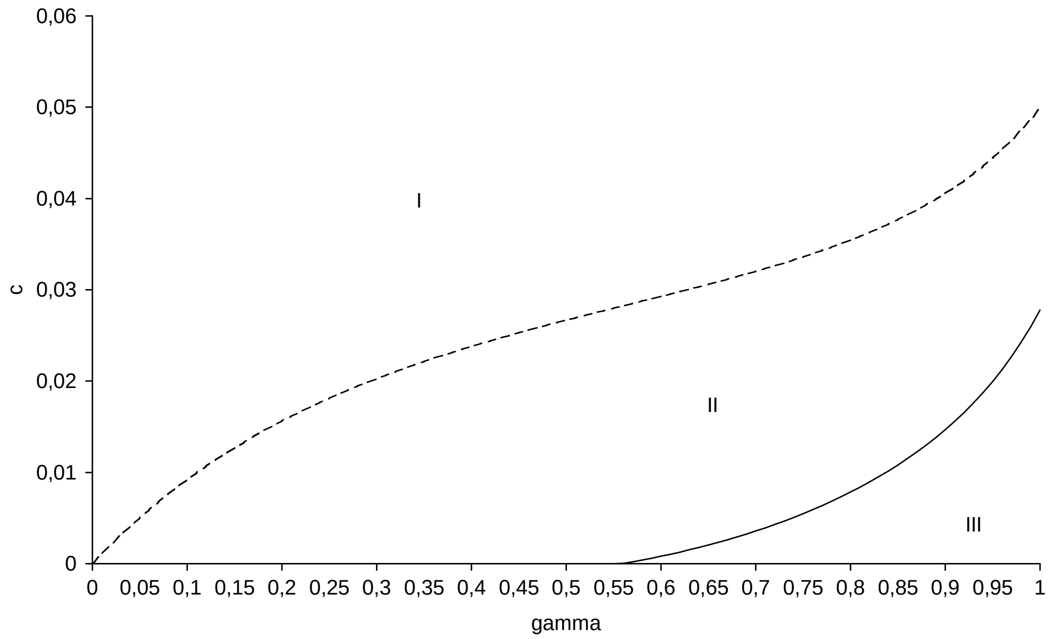
For each access mode, service and infrastructure-based, incumbents' equilibrium offers will involve that choice of y or q, respectively, which maximises their bilateral profits with the entrant. If incumbents are free to choose any access mode, they choose the mode of access that maximises bilateral profits. This implies that we simply have to compare bilateral profits calculated above to find out which entry mode incumbents will choose in equilibrium. In our example, bilateral profits for service based and infrastructure based access are given by

$$\pi_{\text{incumbent}}^{\text{service-excl}} + \pi_{\text{entrant}}^{\text{service-excl}} = \frac{(1-c)^2\left(32 - 3\gamma^4 + 24\gamma^3 - 20\gamma^2 - 32\gamma\right)}{\left(\gamma(4-\gamma^2) + 8(1-\gamma^2)\right)^2}$$

$$\pi_{\text{incumbent}}^{\text{infra-excl}} + \pi_{\text{entrant}}^{\text{infra-excl}} = 2\left(\frac{2-(4-\gamma)c-\gamma}{2\gamma - 2\gamma^2 + 4}\right)^2$$

Figure 4.2 below demonstrates where either access mode dominates from a profit, respectively a welfare point of view. On the thick line in the c, γ plane the two profits are equal, with infrastructure profits exceeding service-based profits below the line, in region III, and service-based profits higher in regions I and II. Infrastructure-based competition dominates service-based competition only for small costs c and low level of differentiation (high γ).

Figure 4.2 Boundary between equilibrium modes of access in the costs/differentiation plane; in region I service-based access dominates, in region III infrastructure-based access does. In region II the market chooses a different access regime than a welfare optimising regulator.



This result is consistent with intuition: the benefit of infrastructure-based access over service-based access is that firms can strategically commit to oversupply the market, by delegating capacity choice to the entrant. This effect is larger when products are more homogeneous (high γ). On the other hand, economies of scale favour service based access. Such economies of scale are lower for low c. So far, we have restricted our analysis to exclusive contracts. In appendix C.1, we show that this result remains valid if we allow for contracts with common representation (where the entrant signs a contract with both incumbents).

We also calculated (see appendix D) what type of access a regulator would mandate, if it would optimise combined firms' and consumers' surplus. On the dashed line, combined surplus in case of service-based competition equals combined surplus in case of infrastructure-based competition. Below this line, in regions II and III, infrastructure-based competition dominates, above the line, in region I, service-based competition dominates.

5 Conclusion

In this paper, we analyse entry into wireless telecommunications markets, where radio spectrum is an essential but scarce input. When this essential input is in the hands of oligopolistic incumbents, entrants have to either negotiate access to an incumbent's infrastructure (service-based access), or access to part of the spectrum itself, allowing them to build their own infrastructure. Increased competition that results from entry into the market generically erodes the incumbents' profits. We find that as long as the entrant's profits outweigh the loss in profits of the incumbent that provides access, entry will take place. Moreover, both incumbents compete away the gains in joint profits, and in equilibrium may be worse off than without entry.

At first sight, the loss of economies of scale in infrastructure-based entry imply that i) aggregate capacity investment under infrastructure based access will be lower than for service-based access, and ii) both entrant and joint profits will be reduced. This would suggest that for incumbents offering service-based access would be a dominant strategy, and that the implementation of spectrum trade would not affect firm behaviour.

However, commitment properties of both types of access are different. In particular, outside observability of contracted quantities between an incumbent and an entrant is arguably lower under service-based entry than under infrastructure-based entry. Under the former, contracted capacities are specified only in a bilateral private contract, while spectrum rights will typically be administered by a public spectrum authority. Also the fact that multiple parties' investments will be observed contributes to outside monitoring of capacity decisions. If indeed such commitment effects are stronger under access to spectrum, rather than access to network capacity, then there will be a trade-off between both types of access. If both product heterogeneity between incumbent and entrant and economies of scale in network investment are large, service-based access will remain the optimal strategy for spectrum incumbents. Conversely, if scale effects are small and products are relatively homogeneous, so that benefits of multiple retail channels are low, incumbents may prefer infrastructure based access. Because the delegation of the capacity decision to the entrant allows an incumbent and entrant jointly to commit to a larger capacity, the rival incumbent will reduce its capacity choice. In this way, the incumbent and the entrant increase joint profits at the expense of the rival.

In our example, we assumed exogenous differentiation of the entrant's retail service. If the network that provides access influences the differentiation of the entrant's product, a so-called cannibalisation effect may occur (Ordover and Shaffer, 2007). The entrant would may then disproportionately cannibalise on the market share of the incumbent that provides entry, compared to the competing incumbent that does not provide entry. While such a circumstance does not alter our general conclusion that, in our Cournot setting, entry is allowed as long as it increases bilateral profits, this could affect the choice between the modes of access. In particular, if the entrant's product is more strongly differentiated from the incumbent under infrastructure-based entry, this mode of access could dominate over a larger range of parameters.

A desirable extension of our model would be to allow for multiple entrants. If the entrants operate in distinct markets and do not effectively compete, this extension is straightforward. Allowing for competition between entrants significantly complicates the analysis. In that case externalities are introduced between various downstream entrants as well, and optimal contracts may also involve exclusivity clauses restricting an incumbent to sell to multiple entrants (so-called ‘input foreclosure’). Equilibrium in contracting games with externalities where both sides of the market (i.e. incumbents and entrants, in our case) consist of multiple players is still poorly understood (see e.g. Whinston, 2006, chapter 4 for a discussion of the issue, and Spector, 2007 for recent progress in this direction).

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Appendix A Proof of claim 1

Proof. First of all, it is clear that access will be provided if and only if this increases bilateral profits of the incumbent and the entrant. If no access were given (by either incumbent) an incumbent could always profit by providing access and using the transfer t_i to appropriate the additional joint profits, leaving the entrant indifferent. A similar argument shows that the traded quantity of capacity y or spectrum q is such that it maximises joint bilateral profits. So let us look at the equilibrium payments for these quantities, t_1 and t_2, that incumbents $V_{1,2}$ ask from the entrant. Assume that it is V_1 's contract that is accepted by the entrant. We have that

$$\pi_E^{(1)} - t_1 = \pi_E^{(2)} - t_2 \tag{A.1}$$

The left-hand side cannot be smaller than the right-hand side, or the entrant would accept V_2's offer. And the left-hand side cannot be larger than the right-hand side, or V_1 could profitable offer higher t_1 and still have its offer accepted by the entrant. Secondly, we have that

$$\pi_2^{(1)} \geq \pi_2^{(2)} + t_2 \tag{A.2}$$

or V_2 would reduce its required payment, t_2, slightly to be accepted by the entrant. And thirdly,

$$\pi_1^{(1)} + t_1 \geq \pi_1^{(2)}$$

or V_1 would prefer to have its offer rejected by the entrant. We combine these three conditions, and furthermore focus on the equilibrium where A.2 holds with equality (as this makes both incumbents better off; any other equilibrium would not be coalition-proof). The first two conditions then imply

$$t_2 = \pi_2^{(1)} - \pi_2^{(2)}$$
$$t_1 = \pi_E^{(1)} - \pi_E^{(2)} + \pi_2^{(1)} - \pi_2^{(2)}$$

leading to the pay-offs as described, while the final condition implies that for this equilibrium to exist we need that

$$\pi_1^{(1)} + \pi_2^{(1)} + \pi_E^{(1)} \geq \pi_1^{(2)} + \pi_2^{(2)} + \pi_E^{(2)}$$

which proves the remaining point. ∎

Appendix B Monopoly with linear demand

We analyse the game with a monopolist incumbent for a particular example, with linear demand $p_I = 1 - x - \gamma y$ and $p_E = 1 - y - \gamma x$. We further assume costs $c(x,q) = c\frac{x}{q}$, linear in x, and exhibiting economies of scale in q. We first analyse the service-based access game, and then turn to infrastructure-based competition. The monopolist will in the end choose the access type which maximises his profits.

In the case of service based competition the monopolist produces at costs cx (i.e. we have $q = 1$). Given the capacity contracted to the entrant, y, the monopolists' best response own capacity is $r(y) = (1 - y\gamma - c)/2$. The incumbent therefore chooses y to optimise $\pi_I(r(y), y) + \pi_E((r(y, y)) = (1 - r(y) - \gamma y)r(y) - c(r(y) + y) + (1 - y - \gamma r(y))y$. The solution is $y = (2 - 2\gamma)(1 - c)/(4 - 3\gamma^2)$ and $x = (1 - c)\left(\gamma^2 + 2\gamma - 4\right)/\left(6\gamma^2 - 8\right)$. The monopoly can appropriate the entire entrant's profits using the fixed transfer, and as a result monopolist's profits equal

$$\pi_I^S + \pi_E^S = \frac{1}{4(4 - 3\gamma^2)}(1 - c)^2\left(8 - 8\gamma + \gamma^2\right)$$

In the case of infrastructure based competition, the monopolist chooses q to optimise $\pi_I(x(q), y(q), q) + \pi_E(x(q), y(q), 1 - q)$, where $x(q), y(q)$ are the equilibrium quantities produced if the monopolist has sold q units of spectrum to the entrant, i.e., the Nash equilibrium in quantities when the incumbent's profits are $\pi_I(x, y) = (1 - x - \gamma y)x - cx/(1 - q)$ and the entrants profits are $\pi_E(x, y) = (1 - y - \gamma x)y - cy/q$. The solution is $q = 1/2$, where $x = y = (1 - 2c)/(\gamma + 2)$ and total profits equal to[2]

$$\pi_I^I + \pi_E^I = \frac{2(1 - 2c)^2}{(\gamma + 2)^2}$$

It is straightforward to check that $\pi_I^S + \pi_E^S > \pi_I^I + \pi_E^I$ for $\gamma \in (0, 1)$.

[2] Provided it is a global maximum, i.e. total profit is larger than pure monopoly profits, $\pi_I^I + \pi_E^I > (1 - c)^2/4$.

Appendix C Common representation

In the main text we considered effectively exclusive equilibria, where either V_1 or V_2 dealt with the entrant, but not both. This might be a realistic situation if relation specific costs are high, and bilateral contracts between entrant and both incumbents would be prohibitively costly. If such costs are not particularly high, contracts with only one provider may still result under explicit exclusivity clauses. As argued in Bernheim and Whinston (1998), common representation equilibria (where both incumbents supply the entrant) dominate exclusive equilibria whenever total *industry profits* under common representation exceed industry profits under exclusive contracts. In particular, this is the case whenever there are no contracting externalities among the two incumbents, that is, when V_1's profits (excluding transfers) do not depend on y_2 (or q_2), and vice versa. This would for example be the case if the two vertically integrated firms operate in distinct markets. In general, however, in our set-up the fact that both incumbents compete with the entrant in the downstream market leads to contracting externalities, and there may exist situations where exclusive contracts dominate common representation.

Here, we consider the possibility of common representation equilibria. We describe the relevant contracts and the conditions determining equilibrium capacities or spectrum quantities, and work these out for the example under consideration.

C.1 Common representation contracts

We now allow for acceptance of contracts from both incumbents. We use the notation π_1^c, π_2^c and π_E^c for equilibrium profits excluding transfers for the three players in this configuration. Denote total profits by $\Pi^c \equiv \pi_1^c + \pi_2^c + \pi_E^c$. We again denote joint profits of incumbent and entrant under the exclusive contract by $\Pi^{(i)}$, if incumbent V_i provides access. A straightforward adaptation of the results in Bernheim and Whinston (1998) similar to the one in appendix A for this case leads to the following

Claim 2. *Common access, where both incumbents contract with the entrant, is an equilibrium only if total sector profits Π^c exceed those under exclusive equilibrium. In that case, the common access equilibrium is preferred to exclusive representation by both incumbents. Equilibrium pay-offs (after transfers) are*

$$\begin{aligned} E:&\quad \Pi^{(1)} + \Pi^{(2)} - \Pi^c \\ 1:&\quad \Pi^c - \Pi^{(2)} \\ 2:&\quad \Pi^c - \Pi^{(1)} \end{aligned}$$

The derivation of this claim relies on the observation that the rents left to the entrant should be sufficiently high to ensure that neither incumbent can deviate to an exclusive contract and leave both entrant and itself better off.

C.2 Access under common representation

The analysis of equilibrium under both modes of access under common contracts is slightly complicated: both firms may offer service-based access (capacities $y_{1,2}$) or infrastructure-based access (spectrum $q_{1,2}$), or one firm (say V_1) may offer service-based and the other (V_2) infrastructure-based access[3]. In this latter hybrid structure, the entrant's total capacity consists of the leased capacity y_1 plus any quantity x_E it produces using its spectrum rights q_2.

We proceed by writing the optimisation problems for both firms. We distinguish the three cases (service-service, infra-infra and hybrid), and for each case determine the conditions for optimum capacity or spectrum choices. Each incumbent will choose its offer such that bilateral profits with the entrant are maximised, given its rival's (accepted) offer.

If both firms offer service-based access, again neither incumbent V_i observes his rival's bid y_j. Either incumbent's choice of x_i^c, y_i^c optimises bilateral profits with the entrant, given the competitor's choice x_j^c, y_j^c. Again, the incumbents cannot just choose any combination x_i^c, y_i^c that is a best response to its rival's choices. The incumbent will behave opportunistically when competing in the retail market, and the entrant will only accept a contract that takes into account this opportunistic behaviour. Therefore x_i^c has to be an optimal response to the triplet y_i^c, x_j^c, y_j^c for the incumbent when competing in the retail market. The common equilibrium in which both V_1 and V_2 supply the entrant, therefore involves quantities x_i^c,y_i^c and x_j^c,y_j^c satisfying the joint conditions for i and $j \neq i$:

$$\begin{aligned} & x_i^c, y_i^c \in \arg\max_{x_i, y_i} \left[\pi_i(x_i, x_j^c, y_i, y_j^c) + \pi_E(x_i, x_j^c, y_i, y_j^c)\right] \\ & \text{s.t. } x_i^c \in \arg\max_{x_i} \left[\pi_i(x_i, x_j^c, y_i^c, y_j^c)\right] \end{aligned} \tag{C.1}$$

If both firms offer infrastructure-based access, all players can observe contracted quantities of spectrum, $q_{1,2}$. Spectrum offers $q_{1,2}$ are chosen to maximise incumbent-entrant bilateral profits, subject to the final stage equilibrium $x_{1,2,E}^c(q_1, q_2)$. So, V_1 andV_2's spectrum offers q_1^c and q_2^c satisfy

$$\begin{aligned} & q_1^c \in \arg\max_{q_1} [\pi_1(x_1^c, x_2^c, x_E^c, q_1, q_2^c) + \pi_E(x_1^c, x_2^c, x_E^c, q_1, q_2^c))] \\ & q_2^c \in \arg\max_{q_2} [\pi_1(x_1^c, x_2^c, x_E^c, q_1^c, q_2) + \pi_E(x_1^c, x_2^c, x_E^c, q_1^c, q_2))] \end{aligned}$$

where the common equilibrium quantities $x_{1,2,E}^c(q_1, q_2)$ as functions of q_1 and q_2 are the Cournot quantities as determined by

$$x_1^c(q_1, q_2) \in \arg\max_{x_1} [\pi_1(x_1, x_2^c, x_E^c; q_1, q_2)] \tag{C.2}$$

[3] We ignore the possibility that a single firm might offer both capacity and spectrum.

and likewise for x_2^c and x_E^c, where

$$\begin{aligned}
\pi_1(x_1,x_2,x_E;q_1,q_2) &= p_1(x_1,x_2,y_1)x_1 - c(x_1,1-q_1)\\
\pi_2(x_1,x_2,x_E;q_1,q_2) &= p_2(x_1,x_2,y_1)x_2 - c(x_2,1-q_2)\\
\pi_E(x_1,x_2,x_E;q_1,q_2) &= p_E(x_1,x_2,x_E)x_E - c(x_E,q_1+q_2)
\end{aligned}$$

Finally, we consider a hybrid equilibrium. We assume w.l.o.g. that V_1 makes a service-based offer y, and V_2 makes an infrastructure-based offer q. Again we assume q is observable while y is not. In practice this is equivalent to saying that y will be chosen after q. This implies that y_1^c, q_2^c solve the following two stage game: in the first stage,

$$q_2^c \in \arg\max_{q_2} [\pi_2(x_1^c,x_2^c,x_E^c,y_1^c;q_2) + \pi_E(x_1^c,x_2^c,x_E^c,y_1^c;q_2))]$$

and in the second stage,

$$\begin{aligned}
x_1^c(q_2), y_1^c(q_2) &\in \arg\max_{x_1,y_1} [\pi_1(x_1,x_2^c,x_E^c,y_1;q_2^c) + \pi_E(x_1,x_2^c,x_E^c,y_1;q_2^c)]\\
x_2^c(q_2) &\in \arg\max_{x_2} [\pi_2(x_1^c,x_2,x_E^c,y_1^c;q_2)]\\
\text{s.t. } x_1^c(q_2) &\in \arg\max_{x_1} [\pi_1(x_1,x_2^c,x_E^c,y_1^c;q_2)]\\
x_E^c(q_2) &\in \arg\max_{x_E} [\pi_E(x_1^c,x_2^c,x_E,y_1^c;q_2)]
\end{aligned}$$

where V_1 and the entrant observe y_1, but V_2 doesn't.

Example

We again consider our example with linear demand, symmetric firms, differentiated goods and constant marginal costs of production. If both incumbents offer service-based access, we find that the market outcome under common contracts is the same as under exclusive contracts: any $y_1 + y_2 = y_1^*$ is an equilibrium (where y_1^* was given in equation 4.2), and profits after transfers are the same in each of these equilibria. The reason is that, in our specific example, only the total quantity $y_1 + y_2$ produced by the entrant matters for each incumbent's choice of quantity x_1. For linear and symmetric costs, each incumbent will want to set the entrant's total quantity $y_1 + y_2$ equal to the value y_1^* obtained in case of exclusive contracts.

Next, we consider a common equilibrium where both incumbents offer infrastructure-based access, i.e., where firm 1 sells capacity q_1 and firm 2 sells capacity q_2. Again competition in the final stage of the game boils down to Cournot competition with asymmetric costs, with $c_1 = cx_1/(1-q_1)$, $c_2 = cx_2/(1-q_2)$ and $c_3 = cx_3/(q_1+q_2)$. We find that in the contracting stage there are three candidates for symmetric equilibria: $q_1 = q_2 = 1/3$, $q_1 = q_2 = 1$ and $q_1 = q_2 = 0$. We focus on the first one, the latter leading to degenerate situations of monopoly and duopoly. The $(1/3, 1/3)$ configuration is an equilibrium only if deviation by either incumbent to $q_i = 0$ or $q_i = 1$ does not lead to higher bilateral profits. This is the case for c and γ

sufficiently small. However, it should also be unprofitable for one of the incumbents to deviate by offering service based access. It turns out that this equilibrium is not stable against such a deviation.

Finally, we consider the hybrid common equilibrium, where incumbent V_1 offers service based access and sells a quantity y to the entrant and V_2 offers infrastructure based access and sells capacity q to the entrant. Because y is unobservable to V_2, y is effectively chosen after q is observed. We find that in such an equilibrium, y will always be chosen such that x_E equals zero, and in turn this implies that optimal q equals 0. Therefore, the hybrid common equilibrium reduces to the exclusive equilibrium under service based access.

We conclude that, in this specific example, firms will *always* choose service based access (in which case they are indifferent between exclusive and common contracts, each leading to identical pay-offs), unless exclusive infrastructure based contracts dominate. Thus, considering common contracts in this explicit example does not affect the results obtained in the absence of such contracts.

Appendix D Choice of access type by a regulator

We assume that the regulator optimises the sum of consumer and firm surplus

$$W = U(x_1, x_2, y) - p_1 x_1 - p_2 x_2 - p_E y + \pi_1 + \pi_2 + \pi_E$$

Using the results for the x_i and y in case of service-based competition and exclusive and common contracts, and for infrastructure-based competition in case of exclusive and common contracts, we find that

$$
\begin{aligned}
W_{SE} &= W_{SC} = \frac{(c-1)^2}{\left(\gamma(4-\gamma^2)+8(1-\gamma^2)\right)^2}\left(\gamma^5+11\gamma^4+36\gamma^3-84\gamma^2-32\gamma+72\right)\\
W_{IE} &= \frac{1}{8\left(2+\gamma-\gamma^2\right)^2}(14c^2\gamma^3-39c^2\gamma^2-20c^2\gamma+108c^2-20c\gamma^3+50c\gamma^2\\
&\quad +40c\gamma-120c+6\gamma^3-15\gamma^2-12\gamma+36)\\
W_{IC} &= \frac{3}{32\left(\gamma+1\right)^2}\left(3c-2\right)^2\left(2\gamma+3\right)
\end{aligned}
$$