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Access Regulation and the Adoption of VoIP [a]

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Abstract in English

The introduction of packet-switched telephony in the form of VoIP raises concerns about current regulatory practice. Access regulation has been designed for traditional telephony on PSTN networks. In this paper, we analyze the effect of access regulation and retail price regulation of PSTN networks on the adoption of a new technology in the form of VoIP. In particular, we show that with endogenous consumer choice between PSTN and VoIP telephony, higher prices for terminating access to the PSTN network make VoIP less likely to succeed and lead to lower profits of operators that offer VoIP telephony exclusively.

JEL-Classification: L96, L51, L13.
Keywords: telecommunications, voice over broadband (VoB), voice over Internet protocol (VoIP), entry, access, regulation, imperfect competition.

Abstract in Dutch

De introductie van pakketgeschakelde telefonie in de vorm van VoIP leidt tot zorgen over de huidige vorm van regulering. Toegangsregulering is ooit ontworpen voor traditionele telefonie op PSTN-netwerken. In dit paper analyseren we de effecten van toegangs- en eindgebruikersprijsregulering van PSTN-netwerken op de adoptie van een nieuwe technologie in de vorm van VoIP. In het bijzonder laten we zien, onder endogene consumentenkeuzen tussen PSTN en VoIP, dat hogere tarieven voor gespreksafgifte op het PSTN-netwerk leiden tot een lagere kans van slagen voor VoIP en tot lagere winsten van operators die alleen VoIP aanbieden.

Steekwoorden: telecommunicatie, spraak over Internet protocol (VoIP), toetreding, toegangsregulering, imperfecte concurrentie.

Contents

Summary

With the emergence of voice telephony based on the Internet protocol (IP), generally known as "voice over IP"or VoIP, the telecommunications landscape is rapidly changing.This new technology, which is fundamentally different from telephony over the public switched telephone network (PSTN), is providing a new impetus to local loop unbundling (LLU) and also stimulates entry into telephony markets by cable operators. Incumbent operators are facing a serious threat, and face the question of whether they should milk the PSTN as long as possible, or introduce VoIP at the cost of cannibalizing PSTN revenues, in the hope of at least partially deterring entry of new operators.

This paper explores imperfect competition between an incumbent and an entrant. While the incumbent, with a history in PSTN telephony, has a complete local access network,the entrant is either a cable operator with a full-coverage broadband network or a newcomer who uses LLU to reach end-users.The incumbent offers PSTN voice telephony to one segment of customers, as well as VoIP services to another segment, while the entrant only offers VoIP services in the latter segment. We consider endogenous migration between the segments, so that consumers can choose between staying with the PSTN network versus adopting VoIP services. Since consumers have to change equipment at their premises, migration decisions are "lumpy "and thus not based on expected prices.

In this set-up, we explore competition in a market for voice telephony between an incumbent trying to balance its tactics with regard to PSTN and VoIP telephony, and an entrant without ties to the past. In particular, we analyze the effects of PSTN regulation. Regulatory authorities in Europe are currently struggling with the question whether they should restrict the incumbent´s activities with regard to VoIP, or refrain from intervening so that the market will determine how this new technology will develop. Regulation may be necessary in order to prevent anticompetitive behavior, but on the other hand, intervening may easily distort the development and adoption processes of innovation.

Our key findings are as follows. The first one relates to retail pricing. The PSTN retail price only affects competition in the VoIP segment as a consequence of the endogenous nature of consumers´technology adoption decisions. An important result is that, as long as the PSTN access price is positive, a higher price for PSTN telephony leads to lower prices for VoIP telephony. Only for an access price equal to zero, the retail price level of PSTN telephony does not affect retail prices for VoIP telephony. These results illustrate the links between different telephony networks,links that should not be ignored by regulators. These links have been explored in detail. Suppose that an entrant in the VoIP market faces a positive access price. This access price may or may not reflect marginal cost levels; it is only important that this access price is positive. Then a lower regulated PSTN price leads to a smaller customer base for VoIP telephony and softens price competition among VoIP operators.

Our second finding relates to access pricing. Access regulation on the PSTN network affects the VoIP market. For instance, if the incumbent charges for call termination on the PSTN and VoIP networks use bill-and-keep, then a higher access price for call termination on the PSTN network leads to a smaller customer base for VoIP telephony. In the context of access price regulation it is important that regulators take into account these linkages between different market segments, and that regulation within one segment may have spillover effects to other segments. In markets in which the PSTN retail price is not regulated (and in which an incumbent enjoys market power), a higher access price leads to higher VoIP retail prices (as in the regulated case) but tends to lead to lower retail prices in the PSTN segment. This suggests that regulation has winners and losers: consumers of the “old ”technology are the winners from a high access price (which can be seen as a protective measure for the old technology) and consumer of the “new ”technology are the losers.

1 Introduction

With the emergence of voice telephony based on the Internet protocol (IP), generally known as "voice over IP" or VoIP, the telecommunications landscape is rapidly changing. This new technology, which is fundamentally different from telephony over the public switched telephone network (PSTN), is providing a new impetus to local loop unbundling (LLU) and also stimulates entry into telephony markets by cable operators. Incumbent operators are facing a serious threat, and face the question of whether they should milk the PSTN as long as possible, or introduce VoIP at the cost of cannibalizing PSTN revenues, in the hope of at least partially deterring entry of new operators.

This paper explores imperfect competition between an incumbent and an entrant. While the incumbent, with a history in PSTN telephony, has a complete local access network, the entrant is either a cable operator with a full-coverage broadband network or a newcomer who uses LLU to reach end-users.[1] The incumbent offers PSTN voice telephony to one segment of customers, as well as VoIP services to another segment, while the entrant only offers VoIP services in the latter segment. We consider endogenous migration between the segments, so that consumers can choose between staying with the PSTN network versus adopting VoIP services.[2] Since consumers have to change equipment at their premises, migration decisions are "lumpy" and thus not based on expected prices.

In this set-up, we explore competition in a market for voice telephony between an incumbent trying to balance its tactics with regard to PSTN and VoIP telephony, and an entrant without ties to the past. In particular, we analyze the effects of PSTN regulation. Regulatory authorities in Europe are currently struggling with the question whether they should restrict the incumbent's activities with regard to VoIP, or refrain from intervening so that the market will determine how this new technology will develop. Regulation may be necessary in order to prevent anticompetitive behavior, but on the other hand, intervening may easily distort the development and adoption processes of innovation.

We address regulation of terminating access as well as the effects that the PSTN retail price may have on market outcomes in the VoIP segment. Accordingly, we do not consider regulation of the VoIP market itself, but look at the broader regulatory picture, which may partly be motivated by considerations of a universal service obligation in the PSTN market, or by market power with regard to call termination on the PSTN. Within the European regulatory framework for communications markets, such considerations—which may be legitimate in a relatively

[1] This is in line with the view that "[...] the real threat to incumbents comes more from cable operators offering cheap (or 'free') VoIP services than from pure-play VoIP companies" (*The Economist*, "Your Television is Ringing - A Survey of Telecoms Convergence", October 14, 2006, p. 10).

[2] We assume that there is full coverage, i.e., all consumers subsribe to either PSTN or VoIP telephony. See De Bijl and Peitz (2006) for an analysis of partial market coverage in a setting that focuses on unbundling.

isolated context—can easily trigger regulatory interventions, such as regulation of the incumbent's access price. However, because of network interconnection, regulators should be aware of the effects that they may have on emerging markets. For a recent policy document on this, see OECD (2006).[3] Our aim is to articulate some of the most salient side effects of current regulatory interventions.

The case of imperfect competition is more realistic than a more stylized set-up with a competitive fringe that needs to purchase the essential input from the incumbent. In practice, entry immediately tends to generate some discipline on incumbents. In such a situation, supposing that VoIP operators use "bill-and-keep" or some other predetermined scheme for call termination, we analyze the competitive effects of terminating access at the PSTN network. In particular, we consider access that is not priced at its marginal cost level. The key insight is that a change of the access price not only generates direct but also indirect cost effects, since it triggers changes in market shares which feed back into changes in perceived marginal costs. This implies that VoIP adoption strongly relies on the level of the terminating access price to the PSTN segment. We will summarize our main results in the concluding section of the paper.

Terminating access in telecommunications networks has been recently analyzed in situations in which operators need mutual access. This literature on two-way access includes the seminal papers by Armstrong (1998) and Laffont, Rey and Tirole (1998); overviews are provided by Laffont and Tirole (2000), Armstrong (2002), Vogelsang (2003), and Peitz, Valletti and Wright (2004). Our paper builds on that literature by analyzing the emergence of VoIP networks in a PSTN environment, in which the PSTN and VoIP networks are interconnected. In such an environment, "metering" of call traffic may still make sense on the PSTN, but this tends to be different for VoIP calls. Hence the natural starting point is to consider the case in which VoIP operators do not charge for call termination.

Access pricing in a situation of one-way access and imperfect competition (with regulated access prices) has been analyzed by Laffont and Tirole (1994, 1996), Armstrong and Vickers (1998), Lewis and Sappington (1999) and De Bijl and Peitz (2007), among others. Here, access prices can be used as a regulatory instrument to affect retail price levels. If, in particular, the regulator can set different rates for a bottleneck owner and a non-integrated competitor, the regulator may want to subsidize the competitor at the margin to increase competitive pressure (Ebrill and Slutsky, 1990; Lewis and Sappington, 1999). In addition, in an asymmetric market the regulator may want to use the access price to favour the more efficient firm (Armstrong and Vickers, 1998; Lewis and Sappington, 1999; De Bijl and Peitz, 2007).[4]

[3] We will see later that some of the views in OECD (2006), on the link between the PSTN access price and the intensity of competition in the VoIP market, may lead to the wrong conclusions.

[4] The economics literature has also looked at bypass possibilities (see e.g. Armstrong, Doyle and Vickers, 1996; Laffont and Tirole, 1994, 1996). Although VoIP can substitute PSTN telephony, it does not allow for full bypass as long as some consumers stay with PSTN. In our model, with full penetration of VoIP the access problem disappears, whereas at any intermediate situation, terminating access to PSTN remains relevant and bypass is not possible.

Complementary to our paper is Foros (2004). To consider the retail market for Internet access, he models a situation of a vertically integrated firm controlling both local access and providing broadband access, and a downstream Internet retailer. The integrated firm can invest in the capacity of local connections, and given the outcome of that decision, the regulator chooses an access price. The focus of the paper is mainly on regulation as a way to induce the integrated firm to invest efficiently and to deter it from foreclosing the market. Independently written but closely related is Hansen (2006). He addresses regulatory concerns with respect to the migration from fixed to mobile in a model with two-part tariffs. In the light of the emergence of IP-based telephony, we look at flat fees, which are becoming more widespread in use.[5] Advantages of our approach are that (i) we provide explicit solutions for equilibrium values, (ii) our comparative statics results are global, and (iii) we allow for asymmetries between networks. Furthermore, our approach allows us to endogenize all retail prices.

Our finding that the incumbent in many environments benefits from a high access price also connects to the literature addressing the profitability of selling an upstream good to a downstream rival, and the incentives to reduce the quality of access; see Reiffen (1998) and Weisman (1998) for a useful discussion. In that literature, discrimination by a vertically integrated firm (whose access price is regulated) may be profitable if the firms sells close substitutes in the downstream market, and if discrimination is not too costly. We don't consider an upstream and a downstream market, but (i) an incumbent who sells two downstream services, namely PSTN and VoIP telephony, whereas the entrant is active in the VoIP segment only, and (ii) we consider endogenous consumer migration between the segments. Access to the PSTN network in our model is a "one-way" essential input to the extent that we assume that the entrant provides terminating access at no cost. However, since PSTN and VoIP are substitutes, the degree to which this essential input is demanded by the entrant is endogenous and the entrant's perceived marginal cost depends positively on the PSTN market share. This is the key feature of our model, which is absent in the literature on discrimination by a vertically integrated firm.

This paper also contributes to the theory on multiproduct firms in a multidimensional product space; for a review, see Manez and Waterson (2001). We provide a tractable model of multiproduct competition which allows for endogenous formation of market segments and can be solved analytically.

The structure of this paper is as follows. Section 2 motivates and presents the model. In section 3, the model is analyzed. Section 4 concludes the paper and summarizes the results.

[5] E.g., in *The Economist*: "[...] many operators have now done away with call charges altogether and instead offer unlimited local, national and even some international calls for a flat monthly fee." ("Your Television is Ringing - A Survey of Telecoms Convergence", October 14, 2006, p. 10).

2 The model

2.1 Introductory remarks

In the light of the wide number and variety of IP-based telephony products and services, let us clarify the focus of our paper. Our model depicts various competitive situations with an incumbent and an entrant. For instance, it may depict a situation of IP-based transport at the edges of traditional networks, allowing for IP-based offerings from traditional operators. In such a situation, PSTN operators have upgraded their local connections to digital subscriber lines (DSL), enabling broadband Internet access and voice-over-broadband (VoB), for instance offered in a bundle. The model may also depict the roll-out of completely IP-based "next generation networks", such as BT's 21st Century Network. In our set-up, this implies that the incumbent is upgrading its network from a PSTN to an all-IP network; during this transition, it offers both PSTN and IP-based telephony.

The model allows for entrants with or without a local network. One possibility is that there is a cable operator (hence an operator with its own local network) offering IP-based services. This is feasible as cable operators may adapt their local lines so that they can carry high-speed two-way traffic, enabling broadband Internet access as well as VoIP telephony. Another option is that the entrant does not have a local network but makes use of local loop unbundling (LLU).[6] If the incumbent's local network is unbundled, entrants without their own local loops can lease unbundled local lines from the incumbent and offer broadband Internet access or VoIP services to end-users. A third possibility, which is very similar to LLU, is that an entrant without a local network makes use of the incumbent's network through a form of access known as "bitstream access". Also, we assume that if a customer switches to a LLU-based entrant, he or she completely substitutes the PSTN service with the entrant's VoIP service. Hence our analysis captures "naked" DSL (also known as "standalone" DSL), a service proposition in which an entrant provides only a broadband Internet connection based on DSL (typically priced at a flat rate) by leasing only the broadband part of the frequency spectrum of the copper wire. Accordingly, the narrowband part of the line is no longer used.

The emergence of VoIP may radically change operators' wholesale deals on call termination. With IP-based telephony, the rationale behind termination charges is undermined, as the marginal cost of call termination is drastically reduced, and VoIP calls are often not metered anymore. Nevertheless, calls from an entrant's VoIP network to the incumbent's PSTN network are delivered at a traditional circuit-switched interconnection point or through a "gateway", which allows for straightforward identification of incoming calls, and, hence, for termination

[6] For an overview of the development of LLU throughout Europe and the European regulatory framework, see De Bijl and Peitz (2005).

charges. Accordingly, for calls from an IP-network to a PSTN, a VoIP provider may have to pay for call termination. Such charges inflate the perceived marginal cost for the VoIP provider. In the case of calls from one IP-based network to another, operators may find it more efficient to implement "bill-and-keep" (reciprocal settlement-free call termination), in line with the packet-based nature of VoIP that, to a certain extent, eliminates the logic of metering incoming calls.

In the main part of our analysis, we suppose that the incumbent charges for call termination on its PSTN, and that no termination charges are used for termination to VoIP customers. This is in line with the observation that the cost for termination at the PSTN is typically seen as being positive, whereas call termination on IP-based networks comes virtually without a cost.[7] Hence, we acknowledge the technological characteristics of the new technology, and based on that, try to derive (prescriptive) regulatory implications. Moreover, by doing so, a priori we treat market segments (i.e., technologies) in an asymmetric way. Practice may be different, though; in the Netherlands in the recent past, incumbent KPN charged the same access charge for all call termination (whether terminating on PSTN or IP). Call termination on all other networks is regulated at the same level as KPN's except for cost differences due to economies of scale.[8] To model this situation would require a modification of our model, with the following features: for the incumbent, the difference between PSTN and VoIP would largely become ineffective, while the two firms would be regulated asymmetrically (being allowed to charge different access markups). The situation would then closely resemble asymmetric access regulation while ignoring the technological asymmetry between the segments; a situation which has been explored e.g. in De Bijl and Peitz (2002a, b).

2.2 Description of the model

There are two firms, an incumbent (operator 1) and an entrant (operator 2). The incumbent has a local access network which can be used for PSTN-based telephony as well as IP-based telephony (VoIP). For instance, its local connections have been upgraded to allow for Digital Subscriber Line (DSL) technology, and its (long-distance) backbone to an IP-based network. The entrant uses only IP-based technology to offer voice services. The entrant may be a cable operator with a full-coverage broadband network. Alternatively, it may be using LLU to reach end-users, that is, it leases unbundled local connections from the incumbent. In the latter case, we assume that the line rental of the local loop is regulated at a cost-based level, so that the entrant is on an equal

[7] Such a structure of access prices may be a good approximation of the outcome of negotiations between VoIP and PSTN operators. As stated in an OECD report (OECD, 2006, p. 26), "...it seems likely in reality that VoIP operators might not charge PSTN operators for IP termination while PSTN operators would still charge VoIP operators for the same call in the opposite direction, due to the VoIP providers' weaker negotiation power."

[8] Private communication with regulator OPTA.

footing as the incumbent. This assumption allows us to abstract from regulatory issues related to the wholesale price of LLU. All networks are interconnected, so that any consumer can make calls to any other consumer. Consumers who use the “old” PSTN technology are said to belong to the old segment, while consumers who decide to migrate to the “new” VoIP technology are said to belong to the new segment.

The retail price in the old segment is assumed to be given by p_0 (it is endogenized in section 3.3). For instance, it is set by the regulator or it may be determined by the presence of a competitive fringe in PSTN telephony (e.g. carrier-select based competitors competing on price).[9] Thus we can treat p_0 as a parameter. In the new segment, the operators compete by setting flat fees. Operator i’s retail price for VoIP telephony is denoted by p_i, $i = 1, 2$. Market shares in the segment of the new technology depend on the retail prices, and are denoted by $s_i(p_1, p_2)$, $i = 1, 2$. They will be shown to be continuously differentiable in prices.[10]

We assume zero marginal costs of call termination on a VoIP network.[11] Also, operators do not charge for call termination to a VoIP customer.[12] The marginal cost of call termination on the PSTN network is $c > 0$, and the incumbent charges a termination charge a for call termination to its PSTN customers. Without loss of generality, we set all other costs equal to zero. Access price a is set by a regulator.[13] Since we do not explicitly model the regulator as a player, access price a is an exogenous parameter in our model.

Consumers are heterogeneous with respect to their reluctance to use a new rather than an established technology. The incumbent offers PSTN-based voice telephony to customers with little technological savvy (the old segment), as well as VoIP to the new segment which is open to a new technology, while the entrant only aims at the latter segment by offering VoIP. The group of old consumers is of size λ_0 and the other consumer group of size λ (for now, we will suppress

[9] Even if no actual retail regulation is in place the threat of regulatory intervention may effectively be reflected by an upper bound on the PSTN retail price. When this upper bound is binding our actual analysis applies. An alternative justification for a fixed retail price can be provided in an extended model: Suppose that there is an additional group of consumers with rather homogenous valuations for PSTN telephony, who either subscibe to PSTN telephony or do not subscribe at all. Under some parameter restrictions, it is profit-maximizing for the incumbent to serve all those consumers. This effectively means that the retail price for PSTN telephony can be taken as given.

[10] This implies that the firms’ offerings are imperfect substitutes, which seems to be common in telecommunications (as well as other services markets), for instance due to heterogeneity in brand recognition, corporate images, and consumer switching costs. Also, services offered by operators are offered in different bundles with other services: if the bundles are not the same, they will be considered as imperfect substitutes.

[11] The “true” marginal costs of electronic communications are virtually zero. Nevertheless, in practice, operators allocate fixed costs to traffic, and hence may partly treat these costs as marginal costs when setting prices. Thus, what we call the marginal cost of call termination is in fact the traffic-dependent cost of call termination. These costs are substantially lower for IP networks than for PSTN networks, and therefore we set them at 0 for VoIP calls.

[12] This is in line with the tendency of VoIP providers to use “bill-and-keep” arrangements for call termination, and with the fact that interconnection typically has already been settled at the underlying level of Internet service providers.

[13] For instance, the regulator has determined that the incumbent has “significant market power” in the wholesale access market, and because of that, and in line with the regulatory framework that is in place, applies price controls (this illustration corresponds to the situation in member states of the European Union).

notation expressing the dependence on retail prices). The total size of the market is normalized to 1, so that $\lambda_0 + \lambda = 1$. More precisely, there is a continuum of consumers with mass 1. For instance, consumers in the old segment are narrowband users, whereas consumers in the new segment are broadband users.

Consumers' utility functions: Consumer tastes are described by types (y,t), uniformly distributed on $[0,1] \times [0,1]$. The y dimension describes preferences for operator 1 versus operator 2 (or their brands), and the t dimension reflects consumers' inclinations towards VoIP versus PSTN. A straightforward interpretation is that y captures consumers' loyalty towards operator 1, independent of the service that they purchase. With regard to the other dimension of a consumer's type, if a consumers has type t close to 0 this means that he is more inclined to adopt VoIP, whereas a consumer with t close to 1 is rather reluctant to adopt VoIP. The distance between the addresses of the products and consumer types give the disutility of consumers for the particular offerings, as will be specified below. VoIP services are "located" at points $(0,0)$ and $(1,0)$, and the PSTN service at $(0,1)$ (in fact, with a properly adjusted U_0 the latter could be any point for which the second coordinate is 1). Note that in our setting y not only plays a role when consumers choose between VoIP services, but also when consumers decide whether to purchase PSTN or VoIP services.

Given a flat fee, each consumer may make some number of calls of varying length. We assume that the average number of call minutes per consumer is independent of type (y,t). Without loss of generality, we normalize this number to 1. Moreover, when a consumer makes a call, the receiving consumer may be any other consumer with equal probability, independent of the network they are subscribed to. Accordingly, calling patterns are balanced: the volumes of on-net and off-net calls are proportionate to market shares. This assumption, which is common in the literature, simplifies the analysis and can be seen as the natural benchmark.[14]

Consumers either subscribe to the PSTN service offered by the incumbent firm or to one of the two VoIP offerings. A consumer who purchases PSTN services derives utility $r + U_0 - \tau(1-t) - \theta y - p_0$, where r is the basic utility from telephony and $U_0 \in \mathbb{R}$ is interpreted as a technology-specific utility of PSTN-services relative to VoIP services (which may also include the firm-specific utility, see below). Parameters τ and θ measure the degree of heterogeneity among consumers: a large τ corresponds to a low substitutability between PSTN and VoIP, and a large θ corresponds to a large degree of differentiation between the operators.

A consumer who purchases VoIP services from firm 1 derives utility $r + U_1 - \tau t - \theta y - p_1$, where $U_1 \in \mathbb{R}$ is a brand or firm-specific utility capturing the asymmetry between operators. Similarly, a customer of firm 2 derives utility $r - \tau t - \theta(1-y) - p_2$. We will implicitly assume

[14] Our model is rich enough to capture some crucial elements of the strategic interaction between PSTN and VoIP providers. See Armstrong (2002; section 4.2.1), De Bijl and Peitz (2002a; section III), and De Bijl and Peitz (2002b, section 6.3) for analyses of two-way access problems in which, as in our model, consumers have balanced calling patterns and face flat fees.

that all consumers make a purchase, i.e. r is sufficiently large.

Profit functions, structure of the game and equilibrium: Before consumers learn VoIP prices, they form beliefs about these prices, and based on these beliefs, they decide whether to choose VoIP or PSTN. This is motivated by the observation that technology adoption is a lumpy decision that cannot be easily reversed if actual prices change (however, it is easy to change the provider for a given technology).[15]

Consumers share the same beliefs about VoIP prices. Moreover, as we restrict the analysis to pure strategies, consumer beliefs can be described by a function that attaches probability 1 to one particular price level $\widehat{p}_i$ for firm i, and probability 0 to all other prices $p_i \neq \widehat{p}_i$. To keep the notation simple, we denote beliefs by $\widehat{p}_1$ and $\widehat{p}_2$.

The specification of the profit functions of the operators then follows directly from our assumptions.

$$\begin{aligned}\pi_1(p_1, p_2; a, p_0) = {} & \lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)[p_0 - \lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)c] + \lambda(p_0, \widehat{p}_1, \widehat{p}_2) \\ & \times [s_1(p_1, p_2)(p_1 - \lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)c) + s_2(p_1, p_2)\lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)(a - c)], \\ \pi_2(p_1, p_2; a, p_0) = {} & \lambda(p_0, \widehat{p}_1, \widehat{p}_2)s_2(p_1, p_2)(p_2 - \lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)a).\end{aligned}$$

Profit levels reflect the volumes of on-net and off-net traffic between operator 1's PSTN network and both operators' VoIP networks—volumes that are proportionate to market shares—as well as the wholesale payments for calls terminating on the PSTN network. Note that the entrant's perceived marginal costs depend on the endogenously determined market share λ_0 which in turn depends on (expected) retail prices.

The model has the following time structure:

$t = 0$: The regulator sets access price a and PSTN price p_0 (or alternatively, p_0 is determined by a competitive fringe in the retail market for PSTN telephony), observed by all players.
$t = 1$: Each consumer learns his or her preference parameter $t \in [0, 1]$, reflecting an individual's inclination towards PSTN versus VoIP. All consumers form expectations about VoIP prices $\widehat{p}_1$ and $\widehat{p}_2$.
$t = 2$: Given their preferences and beliefs, consumers choose between PSTN and VoIP. At the same time, the operators (simultaneously) set VoIP prices p_1 and p_2.
$t = 3$: Each consumer learns his or her preference parameter $y \in [0, 1]$, reflecting an individual's inclination towards operator 1 versus operator 2. Consumers observe prices p_1 and p_2 and make purchase decisions, that is, they choose VoIP telephony from the incumbent or from the entrant if they opted for VoIP at $t = 2$. Otherwise, they choose PSTN telephony from the incumbent. Consequently, market shares and profit levels are realized.

[15] Another possibility would be that consumers decide after observing prices *and* their own taste parameters. See the concluding section for a discussion of this alternative specification.

We solve for fulfilled expectations equilibrium, that is, (i) each firm maximizes its profits while taking consumers' beliefs and its rival's strategy as given; (ii) based on beliefs $\widehat{p}_1$ and $\widehat{p}_2$, consumers choose the utility maximizing technology; (iii) consumers' beliefs are fulfilled, so that equilibrium prices p_1^* and p_2^* satisfy $p_1^* = \widehat{p}_1$ and $p_2^* = \widehat{p}_2$, and given the observed prices, consumers who have migrated to VoIP choose the operator that maximizes their utility.[16]

Surplus levels. To be able to discuss the effects of regulation on consumer surplus and welfare, we provide the formulas for calculating various surplus levels in the model. The aggregate surplus of PSTN users is equal to:

$$\begin{aligned} CS^{\text{PSTN}} &= \int_{\lambda^*}^{1} \int_0^1 (r + U_0 - \tau(1-t) - \theta y - p_0) \mathrm{d}y \mathrm{d}t \\ &= [(r + U_0 - \tau - p_0 - \frac{1}{2}\theta)(1-\lambda^*) + \frac{1}{2}\tau(1-(\lambda^*)^2)]. \end{aligned}$$

The aggregate surplus of subscribers to operator 1's VoIP service is equal to:

$$\begin{aligned} CS_1^{\text{VoIP}} &= \int_0^{\lambda^*} \int_0^{s_1(p_1^*, p_2^*)} (r + U_1 - \tau t - \theta y - p_1^*) \mathrm{d}y \mathrm{d}t \\ &= [(r + U_1 - p_1^*) s_1(p_1^*, p_2^*) - \frac{1}{2}\theta s_1(p_1^*, p_2^*)^2]\lambda^* - \frac{1}{2}\tau s_1(p_1^*, p_2^*)(\lambda^*)^2. \end{aligned}$$

The aggregate surplus of subscribers to operator 2's VoIP service is equal to:

$$\begin{aligned} CS_2^{\text{VoIP}} &= \int_0^{\lambda^*} \int_{s_1(p_1^*, p_2^*)}^{1} (r - \tau t - \theta(1-y) - p_2^*) \mathrm{d}y \mathrm{d}t \\ &= [(r - \theta - p_2^*)(1 - s_1(p_1^*, p_2^*)) + \frac{1}{2}\theta(1 - s_1(p_1^*, p_2^*)^2)]\lambda^* - \frac{1}{2}\tau(1 - s_1(p_1^*, p_2^*))(\lambda^*)^2 \\ &= [(r - p_2^*) s_2(p_1^*, p_2^*) - \frac{1}{2}\theta s_2(p_1^*, p_2^*)^2]\lambda^* - \frac{1}{2}\tau s_2(p_1^*, p_2^*)(\lambda^*)^2. \end{aligned}$$

Let $CS^{\text{VoIP}} = CS_1^{\text{VoIP}} + CS_2^{\text{VoIP}}$ Aggregate consumer surplus is equal to $CS = CS^{\text{PSTN}} + CS_1^{\text{VoIP}} + CS_2^{\text{VoIP}}$. Producer surplus is equal to aggregate profits: $PS = \pi_1^* + \pi_2^*$. Welfare is then defined as the sum of consumer and producer surplus: $W = CS + PS$. Note that since technologies and operators differ in their respective costs and gross surplus offered, different allocations lead to different welfare levels. As we see in the next section, the equilibrium allocation is affected by regulation.

[16] It is formally equivalent to analyze subgame perfect equilibria in a game in which, at stage $t = 2a$, consumers first decide simultaneously between PSTN and VoIP, and, at stage $t = 2b$, operators set VoIP prices. See the previous version, De Bijl and Peitz (2006), for a discussion.

3 Analysis

3.1 Main results

We start by looking at consumers' choices at the last stage, $t = 3$, for those consumers who have chosen to adopt VoIP. The consumer who is indifferent between the two VoIP services is located at location $\bar{y}$, given by $U_1 - \theta\bar{y} - p_1 = -\theta(1-\bar{y}) - p_2$. All consumers characterized by parameter $y < \bar{y}$ subscribe to operator 1's service, and all others to operator 2. Accordingly, if a fraction λ demands VoIP services, then the total demand for VoIP offered by firm 1 is

$$\lambda s_1(p_1, p_2) = \lambda \left(\frac{1}{2} + \frac{U_1}{2\theta} + \frac{p_2 - p_1}{2\theta} \right).$$

Note that if $U_1 \geq \theta$, operator 2 must price below operator 1 to capture any market share. This corresponds to a situation in which there is vertical quality differentiation between the two operators and where operator 1 offers higher quality. Correspondingly, if $U_1 \leq -\theta$ operator 2 offers higher quality.

At $t = 2$, consumers expect prices $\widehat{p}_1$ and $\widehat{p}_2$. At this stage, they have learned their locations t but they do not yet know their addresses y.

We can now state the following result (the proof is relegated to the appendix).

Lemma 1. *The expected utility of a consumer of type t who intends to migrate to VoIP is* $r - \tau t - \frac{\theta}{2} - \widetilde{p}(\widehat{p}_1, \widehat{p}_2)$ *where*

$$\widetilde{p}(\widehat{p}_1, \widehat{p}_2) \equiv s_1(\widehat{p}_1, \widehat{p}_2)(\widehat{p}_1 - U_1) + s_2(\widehat{p}_1, \widehat{p}_2)\widehat{p}_2 + \frac{\theta}{2}[s_1(\widehat{p}_1, \widehat{p}_2)^2 + s_2(\widehat{p}_1, \widehat{p}_2)^2 - 1].$$

Function $\widetilde{p}(\widehat{p}_1, \widehat{p}_2)$ will be called the "adjusted average price" for VoIP services. Compared to the average price for VoIP services, it is adjusted in order to take into account the potentially asymmetric utility level U_1 as well as the expected reduction in utility from not consuming the ideal product specification. It is straightforward to show that $\widetilde{p}(\widehat{p}_1, \widehat{p}_2)$ can be simplified into

$$\widetilde{p}(\widehat{p}_1, \widehat{p}_2) = s_1(\widehat{p}_1, \widehat{p}_2)(\widehat{p}_1 - U_1) + s_2(\widehat{p}_1, \widehat{p}_2)\widehat{p}_2 - \theta s_1(\widehat{p}_1, \widehat{p}_2) s_2(\widehat{p}_1, \widehat{p}_2). \tag{3.1}$$

The expected utility derived from staying with the PSTN service is $r + U_0 - \tau(1-t) - \frac{\theta}{2} - p_0$. Accordingly, at $t = 2$, the location $\bar{t}$ of the consumer who, given his beliefs about VoIP prices, is indifferent between PSTN and VoIP services, is implicitly defined by

$$r + U_0 - \tau(1-\bar{t}) - \frac{\theta}{2} - p_0 = r - \tau\bar{t} - \frac{\theta}{2} - \widetilde{p}(\widehat{p}_1, \widehat{p}_2).$$

Therefore, the fraction of consumers opting for VoIP services, that is, all consumers located at $t < \bar{t}$, is given by

$$\lambda(p_0, \widehat{p}_1, \widehat{p}_2) = \frac{1}{2} + \frac{p_0 - U_0 - \widetilde{p}(\widehat{p}_1, \widehat{p}_2)}{2\tau}.$$

The fraction of consumers staying with the PSTN network is then, by definition, equal to $\lambda_0(p_0,\widehat{p}_1,\widehat{p}_2) = 1-\lambda(p_0,\widehat{p}_1,\widehat{p}_2)$.

At $t=2$, for given consumer beliefs, $\lambda(p_0,\widehat{p}_1,\widehat{p}_2)$ and $\lambda_0(p_0,\widehat{p}_1,\widehat{p}_2)$ are fixed. Note that at this stage, again because expectations are given, also function $\widetilde{p}(\widehat{p}_1,\widehat{p}_2)$ can be treated as a constant denoted by $\widetilde{p}$. Then, for given consumer choices with regard to PSTN versus VoIP, it can be shown that the Nash equilibrium at $t=2$ is characterized by the following prices:

$$p_1(p_0,\widetilde{p}) = \frac{3\theta+U_1}{3}+\frac{a}{2}+\frac{\widetilde{p}-p_0+U_0}{2\tau}a, \tag{3.2}$$

$$p_2(p_0,\widetilde{p}) = \frac{3\theta-U_1}{3}+\frac{a}{2}+\frac{\widetilde{p}-p_0+U_0}{2\tau}a. \tag{3.3}$$

Some interim observations can be made from equations (3.2)-(3.3) under the assumption that $\widetilde{p}$ is fixed. Clearly, if the VoIP services are closer substitutes (θ smaller), then lower prices result. Brand loyalty or superior performance of firm 1's VoIP services ($U_1>0$) translate into a higher price p_1. Finally, provided that the last term in the pricing equations is sufficiently small, a higher access price translates into higher prices. Furthermore, firm 2's price-cost margin is not affected by the access price since $p_2 = \frac{3\theta-U_1}{3}+\lambda_0(p_0,\widehat{p}_1,\widehat{p}_2)a$. Hence, for fixed beliefs, the entrant's profits are unaffected by a change in the access price.

Still given the assumption that $\widetilde{p}$ is fixed, we also observe that a higher price in the PSTN segment translates into *lower* prices for VoIP services. This is due to the cost effect that a higher p_0 will lead to less demand for PSTN services, which reduces the likelihood that subscribers to operator 2's VoIP service make use of terminating access to the PSTN network. This corresponds to lower perceived costs for operator 2, and hence, a more competitive outcome. The reverse holds for the adjusted average VoIP price $\widetilde{p}$, and for the fixed-utility advantage of PSTN compared to VoIP services, U_0.

For (3.2)-(3.3) to be an equilibrium, beliefs must be confirmed, that is, it must be that $p_1(p_0,\widetilde{p}) = \widehat{p}_1$ and $p_2(p_0,\widetilde{p}) = \widehat{p}_2$. If we define, based on (3.1),

$$\begin{aligned} g(\widetilde{p}) \equiv\ & s_1(p_1(p_0,\widetilde{p}),p_2(p_0,\widetilde{p}))(p_1(p_0,\widetilde{p})-U_1)+s_2(p_1(p_0,\widetilde{p}),p_2(p_0,\widetilde{p}))p_2(p_0,\widetilde{p}) \\ & -\theta s_1(p_1(p_0,\widetilde{p}),p_2(p_0,\widetilde{p}))s_2(p_1(p_0,\widetilde{p}),p_2(p_0,\widetilde{p})), \end{aligned}$$

then the equilibrium value $\widetilde{p}^*$ is defined as a fixed point of $g(\cdot)$. One can verify that $g(\cdot)$ is linear in $\widetilde{p}$, so that there exists a unique solution:

$$\widetilde{p}^* = \frac{18a\theta(\tau-p_0+U_0)+(27\theta^2-18U_1\theta-U_1^2)\tau}{18\theta(2\tau-a)}.$$

The interpretation is that the quality-adjusted average price for VoIP services is decreasing in U_1 (for θ not too small). For $a>0$, it is increasing U_0, and decreasing in p_0. The latter two properties can be explained by the fact that an decrease in U_0-p_0 makes migration to VoIP more attractive, everything else equal, as explained above. Therefore, in an equilibrium outcome, pricing in the VoIP segment becomes more competitive (and therefore, $\widetilde{p}^*$ falls).

We restrict our analysis to moderate levels of the terminating access price.

Assumption: $a < 2\tau$.

Substituting the constant $\widetilde{p}^*$ into (3.2)-(3.3), we obtain the equilibrium size of the PSTN segment:

$$\lambda_0^* = \lambda_0(p_0, p_1^*, p_2^*) = \frac{9\theta[4(\tau - p_0 + U_0) + 3\theta] - U_1^2 - 18U_1\theta)}{36\theta(2\tau - a)}. \tag{3.4}$$

Using this expression we obtain equilibrium prices for VoIP services.

Lemma 2. *When consumers choose between VoIP and PSTN, equilibrium prices are given by*

$$\begin{aligned} p_1^* &= \theta + \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 30\theta U_1 - U_1^2\} + 24\theta(3\theta + U_1)\tau}{36\theta(2\tau - a)}, \end{aligned} \tag{3.5}$$

$$\begin{aligned} p_2^* &= \theta - \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 6\theta U_1 - U_1^2\} + 24\theta(3\theta - U_1)\tau}{36\theta(2\tau - a)}. \end{aligned} \tag{3.6}$$

If an equilibrium exists, it is unique (given by (3.5)-(3.6)). In order for p_1^* and p_2^* to be profit-maximizing prices, the following second-order condition has to be satisfied:

$$-\frac{U_1^2 + 18U_1\theta + 9\theta(4\tau - 4a + 4p_0 - 3\theta - 4U_0)}{36\theta^2(2\tau - a)} < 0.$$

This condition is equivalent to $\lambda^* > 0$, and is always be satisfied in an interior equilibrium. Using that $a < 2\tau$, it can be rewritten as $a < \frac{1}{36\theta}U_1^2 + \frac{1}{2}U_1 + p_0 - U_0 - \frac{3}{4}\theta + \tau$.

Operator 2's profits in an equilibrium are equal to

$$\pi_2^* = \frac{(3\theta - U_1)^2[9\theta(4\tau + 4p_0 - 4U_0 - 4a - 3\theta) + U_1^2 + 18U_1\theta]}{648\theta^2(2\tau - a)}$$

For $U_1 = 0$ the expression reduces to

$$\pi_2^* = \frac{\theta(4\tau + 4p_0 - 4U_0 - 4a - 3\theta)}{8\theta(2\tau - a)}$$

The equilibrium expression for firm 1's profit is somewhat more involved.

Remark: Since we are interested in the migration from PSTN to VoIP we analyze only interior equilibria. Let us briefly comment on the possibility that full migration to VoIP is an equilibrium. We will see that for a range of parameter constellations there exist multiple equilibria. For a given price p_0, a consumer of type $t = 1$ has expected utility from PSTN-telephony equal to $r + U_0 - \theta/2 - p_0$. In equilibrium his expected utility for VoIP telephony would be $r - \tau - ((s_1^*)^2 + (s_2^*)^2)\theta/2 + s_1^*(U_1 - p_1^*) - s_2^* p_2^*$. Note that in an interior equilibrium a consumer of type $t = 1$ must strictly prefer PSTN. However, in such an equilibrium VoIP prices are higher than in a situation in which all consumers have migrated. Therefore, denoting equilibrium values for $a = 0$ with superscript 0, the condition for the existence of an equilibrium in which all consumers have migrated to VoIP is $r + U_0 - \theta/2 - p_0 < r - \tau - ((s_1^{*0})^2 + (s_2^{*0})^2)\theta/2 + s_1^{*0}(U_1 - p_1^{*0}) - s_2^{*0} p_2^{*0}$.

3.2 Comparative statics

3.2.1 The PSTN terminating access price

Note that for a given number of VoIP customers a higher access charge implies that the entrant faces higher perceived marginal costs and the incumbent a higher opportunity cost to attract customers in the VoIP segment. This shifts the reaction curve of both operators outward. Since products are strategic complements under price competition, retail prices are inflated.[17] Note that higher perceived costs are also passed on to consumers. In particular, $p_2^* - \lambda_0 a = \theta - U_1/3$, which, again, is independent of a and market shares s_i^* are independent of a. However, firm 2's profits are not neutral to the access price. The reason is that consumers, anticipating higher VoIP prices, become more reluctant to migrate to VoIP, that is $\partial\lambda_0^*/\partial a > 0$.[18] Formally, taking derivatives of the expressions reported in equations (3.5) and (3.6), we obtain for $i = 1, 2$,

$$\frac{\partial p_i^*}{\partial a} = \lambda_0^* + \frac{\partial \lambda_0^*}{\partial a} a = \lambda_0^* + \frac{a\lambda_0^*}{2\tau - a} > 0.$$

Prices respond more strongly to changes in the access price if the access price is already high, that is, p_i^* is convex in a:

$$\frac{\partial^2 p_i^*}{\partial a^2} = \frac{\lambda_0^*}{2\tau - a} + \frac{(\lambda_0^* + \frac{a\lambda_0^*}{2\tau - a})(2\tau - a) + a\lambda_0^*}{(2\tau - a)^2} > 0.$$

Consider now the change of firm 2's equilibrium profit in response the change in the access price. The equilibrium profit of firm 2 is decreasing in the access price because

$$\frac{\partial \pi_2^*}{\partial a} = \frac{\partial \lambda^*}{\partial a} [s_2(p_1^*, p_2^*)(p_2^* - \lambda_0^* a)] < 0.$$

Our main comparative statics result can be summarized as follows.

Result 1. *For a given PSTN price, a higher access price for call termination on the PSTN network leads to*

(i) a smaller customer base for VoIP telephony;

[17] Note that in standard models of price competition with differentiated products firms offer strategic complements. This gives rise to monotone comparative statics properties (see e.g. Vives, 1990, and Milgrom and Roberts, 1990). For a recent overview of the literature on strategic complementarites see e.g. Vives (2005). For a first application of the theory to telecommunications markets see Peitz (2005). In our simple price competition model, VoIP prices are indeed strategic complements.

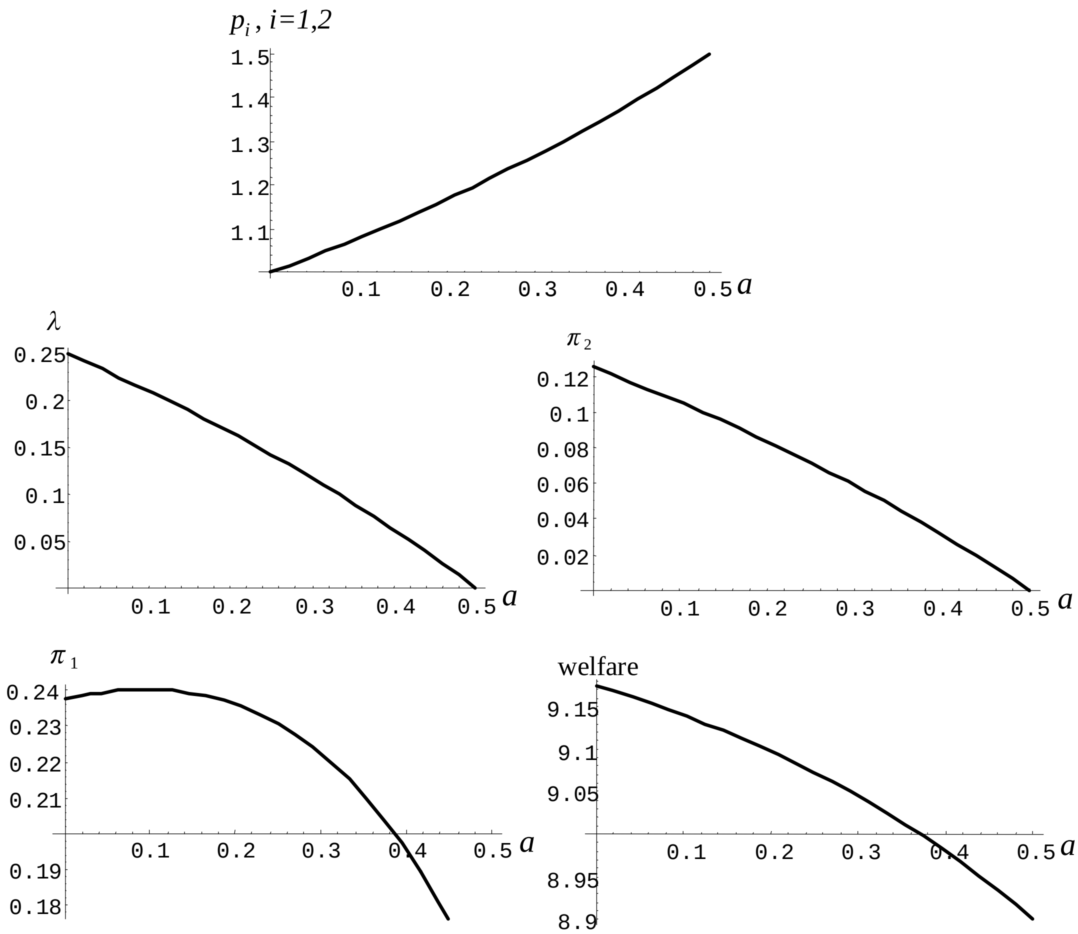
[18] From equation (3.4) it can be directly seen that indeed $\partial\lambda_0/\partial a > 0$ whenever $\lambda_0 > 0$.

(ii) higher prices for VoIP telephony; and

(iii) lower profits for operator 2.

We will illustrate the equilibrium properties with some diagrams based on a numerical example. Suppose that $p_0 = 0.25$, $\theta = \tau = 1$, $r = 10$, $U_0 = U_1 = 0$, and $c = 0.1$. The condition for an interior solution then requires that $a < 0.5$. We will therefore look at the implications for $a \in [0, 0.5]$.[19] Figure 3.1 contains various illustrations of the equilibrium properties.

Figure 3.1 Illustration of the equilibrium outcome when the PSTN retail price is exogenously given



As illustrated in figure 3.1, firm 1's profit may be partly increasing and partly decreasing in the access price a. This is the case for p_0 sufficiently large. For small values of access price a, a PSTN consumer is then in expectations more valuable for firm 1 than a VoIP consumer. Thus, an increase in a which shifts consumers from the VoIP to the PSTN segment is profit increasing. This explains why firm 1's profits are initially increasing in a. This no longer holds for larger a.

[19] We have checked the robustness of the effects on surplus levels by varying parameter values. The qualitative observations discussed above are robust to such changes.

The reason is that for larger a, competition in the VoIP segment is more relaxed so that, for retail prices in the VoIP segment above a certain level, a consumer in the VoIP segment is in expectations more valuable than a consumer in the PSTN segment. Firm 1 may therefore obtain a larger profit with a lower access price since this implies a larger VoIP segment.

This result suggests that it is not necessarily in the interest of firm 1 to lobby for a high access charge. In particular, if p_0 is sufficiently small, then firm 1's profit is globally decreasing in a (note: this is not illustrated in the figure). The reason is the following: With a higher access price a consumers expect the VoIP segment to be less competitive. Therefore only few consumers decide to migrate to the VoIP segment. Since the PSTN-segment is not very profitable, firm 1 would be better off if many consumers would migrate. Interestingly, to the extent that firm 1 can influence U_0 it has no incentive to improve the quality of PSTN services. Rather the opposite is true, since it would like to convince consumers to move to the VoIP segment.

More generally, one can observe that the larger p_0, the larger the profit-maximizing access price. Again the argument is that relaxed competition in the VoIP segment (and thus a smaller market share of VoIP) is in the interest of firm 1 if retail price regulation in the PSTN is less strict (to the effect that PSTN customers are more valuable).

Figure 3.1 shows that total welfare is decreasing in a, which may appear to be surprising as the policy implication is that a should be lower than marginal cost. However, note that we assumed that there is full participation so that retail price levels do not affect participation. This, in turn, implies that all welfare results are driven by the division of the market among PSTN and VoIP, and in the VoIP segment, the division between the two operators. For the specific parameter values that we chose, it turns out that the welfare-maximizing size of the VoIP segment is as large as possible (under the restriction that $a \geq 0$). Finally note that in general VoIP prices are increasing in a. Therefore all consumers are necessarily (weakly) worse off after an increase of the access price.

3.2.2 The PSTN retail price

Recall our assumption that the retail price for PSTN services is regulated. While this is no longer an appropriate description in those countries in which retail regulation has been phased out, it still can be used as a useful benchmark since various forms of wholesale regulation affect retail prices in the PSTN segment (e.g. resale competition limit the incumbent's market power in the retail market). Thus the fixed price for PSTN that we assume in our model, can be seen as a simplification of situations in which the PSTN price is less flexible than VoIP prices, for instance due to regulatory measures that lead to unbundling and resale-based competition in the PSTN segment.

It is interesting to see how our results depend on the level of the PSTN retail price. We can make a number of observations, mostly based on (3.5)-(3.6):

Result 2.

(i) A higher price for PSTN telephony leads to a larger customer base for VoIP telephony.

(ii) Provided that the PSTN access price is positive, a higher price for PSTN telephony leads to lower prices for VoIP telephony.

(iii) Provided that the PSTN access price is zero, a higher price for PSTN telephony does not affect prices for VoIP telephony.

(iv) A higher price for PSTN telephony increases the entrant's profits.

Observation (i) is not surprising: if PSTN telephony becomes more expensive, more consumers will switch to VoIP. Observations (ii)-(iii) can be explained as follows. The mechanism behind the effect

$$\frac{\partial p_i^*}{\partial p_0} = \frac{\partial \lambda_0^*}{\partial p_0} a < 0,\ i = 1,2,$$

is that an increase in p_0 reduces the size of the segment of PSTN customers, which in turn reduces the probability that a customer of operator 2 makes a call to the PSTN network. Hence, because of the reduction in expected access payments to the incumbent, operator 2's perceived marginal cost is reduced. The result is a more competitive outcome in the VoIP segment, as has been explained before. Thus a higher price in the PSTN segment leads to a lower prices in the VoIP segment so that products across segments are strategic substitutes. Note, however, that if the incumbent's access price for termination on the PSTN network is zero, then the entrant's perceived marginal cost remains unaffected if the number of PSTN customers decreases.

An increase in p_0 has the same effect on prices in the VoIP segment as an increase in the fixed utility of PSTN telephony. More precisely, a larger value for U_0 increases the customer base for PSTN services, and hence inflates the entrant's perceived marginal cost. Therefore,

$$\frac{\partial p_i^*}{\partial U_0} > 0,\ i = 1,2.$$

To understand observation (iv), note that the equilibrium profit of firm 2 is increasing in the price of the PSTN-segment,

$$\frac{d\pi_2^*}{dp_0} = -\frac{d\pi_2^*}{dU_0} = \frac{(3\theta - U_1)^2}{18\theta(2\tau - a)} > 0.$$

The reason is that such a higher price leads to more migration to the VoIP segment. This effect is reinforced because such migration leads to lower perceived costs of firm 2 and thus, with fulfilled expectations, makes the VoIP segment more attractive. Due to the expansion of the VoIP segment, the entrant benefits from such a change.

Finally, we turn to the comparative statics properties of firm 1's profits. Firm 1's profit is increasing in p_0 for p_0 small. This is hardly surprising since a high retail price in the PSTN segment directly feeds into profits. A possibly countervailing effect is that firm 1 loses market share in the retail market. However, as long as a consumers in the VoIP segment is in expectations more valuable than a consumer in the PSTN segment, migration from PSTN to VoIP is good news for firm 1. For large p_0 the effect is reversed. Thus, for a given a there is a finite profit-maximizing retail price for PSTN telephony. The reason is that although firm 1 wants to milk its PSTN customers it cannot price too high in order not to loose consumers to VoIP. Thus, strengthening the VoIP segment increases the disciplinary pressure on the PSTN operator in the retail market. Whether this force is sufficiently strong to allow for deregulation of p_0 is an empirical issue.

3.3 Access regulation when the PSTN retail price is endogenous

As an extension of the model, consider two ways in which the PSTN price p_0 may be endogenous.

(i) Resale competition in the PSTN segment: Suppose that due to regulation of the incumbent's originating access price (equal to a_0), there is intense competition in the PSTN segment. Note that each of these entrants faces a perceived marginal cost of $\lambda_0 a + a_0$. Competition then drives down the incumbent's retail price to $p_0 = \lambda_0 a + a_0$. Suppose that for given access prices, equilibrium prices p_1^* and p_2^* have been determined. Then p_0 is obtained as the fixed point of $p_0 = \lambda_0^*(p_0, p_1^*, p_2^*)a + a_0$. Notice that the operators, when choosing prices in the VoIP segment, do not take into account that p_0 affects the size of the VoIP segment (at the moment they choose VoIP prices, consumers already have made their migration decision).

The effect of access price a is now as follows. The access price a does not affect the size of the VoIP segment λ (nor does it affect market shares within that segment). An increase in a leads to higher retail prices in both segments and thus reduces both CS^{PSTN} and CS^{VoIP}. It increases the incumbent's profits while leaving the entrant's profits unaffected. Overall, welfare W is not affected. Accordingly, the model's outcomes are similar to the outcomes of a model in which there is no migration between technologies (see also De Bijl and Peitz, 2006).

(ii) Sequential price setting: Consider the case in which operator 1 is be a monopolist in the PSTN segment and is able to set a profit-maximizing price p_0. We assume that operator 1 chooses p_0 after all parameters are set but before the rest of the game evolves. Hence the incumbent takes into account the equilibrium prices from competition in the VoIP segment by using backward induction.[20]

Given the PSTN access price and the equilibrium outcome in the VoIP segment, operator 1 chooses p_0 to maximize profits $\pi(p_1^*, p_2^*; a, p_0)$. One can show that this profit function is concave in p_0. More precisely, it is quadratic, and one can show that $p_0^* = \frac{1}{144\tau\theta}[36a^2\theta - 3a(U_1^2 + 10U_1\theta - 3\theta(-4c + 4U_0 + \theta - 4\tau)) + 2\tau(U_1^2 - 6U_1\theta + 9\theta(4c + 4U_0 + 5\theta + 4\tau))]$.

[20] This timing can be motivated by the fact that the incumbent is less flexible in setting PSTN prices than in setting VoIP prices. E.g., because of universal service obligations, the incumbent may need to obtain regulatory approval.

The following result, which we state without proof, confirms Result 2 for the case that the PSTN retail price is not fixed:

Result 3. *For endogenous p_0, a higher access price for call termination on the PSTN network leads to*
(i) a smaller customer base for VoIP telephony;
(ii) higher prices for VoIP telephony; and
(iii) lower profits for operator 2.

We briefly discuss some equilibrium properties; for a numerical illustration, see De Bijl and Peitz (2006). The PSTN price p_0^* may be decreasing or increasing in access price a, and $p_0^*(a)$ may be U-shaped. This can be explained as follows. The incumbent makes profits from selling wholesale access in the PSTN segment, and from selling retail services both in the PSTN and the VoIP segment. Recall that an increase in the access price (for given p_0) leads to higher VoIP prices. Hence for a given p_0, a higher access price reduces the VoIP segment. However, the incumbent can adjust p_0. For low levels of a, an increase feeds only weakly into higher VoIP prices. Since PSTN customers are very valuable at low levels of a, it is profit maximizing for the incumbent to reduce p_0. At higher levels of a an increase feeds strongly into higher VoIP prices, as VoIP consumers are, in expectation, rather valuable for the incumbent. He therefore reduces the reduction of the size of the VoIP segment (the reduction that would occur with a constant p_0) by increasing its PSTN price.

Note that in general, a higher terminating access price a leads to larger PSTN segment. For relatively low levels of the access price, the incumbent decreases its PSTN price to benefit from an even larger PSTN segment. This implies that PSTN consumers benefit from a moderately high access price. VoIP customers suffer and there is less migration to VoIP. To the extent that our model approximates current telecommunications markets in which the incumbent enjoys market power in the PSTN segment, our findings run counter to the view that a higher access charge would lead to a decline of the PSTN segment; for instance, a recent OECD report (OECD, 2006, p. 28) contains a statement to this effect.

Note that total welfare is concave in a. To see this, recall that welfare results are driven by the division of the market among PSTN and VoIP, and in the VoIP segment, the division between the two operators. The regulator may use a to implement the optimal split between the segments, which explains why the optimal access price need not be equal to marginal cost.

4 Conclusion

In this paper, we have explored competition between an incumbent offering both PSTN and VoIP telephony, and an entrant active only in the VoIP segment. Our analysis has shed light on the effects of regulation in one segment on competition in another, unregulated segment, and has focused on cost effects of access price regulation. Given the publication of reports such as OECD (2006), this type of analysis is urgently called for.

We shortly discuss our main results, first with respect to the regulation of the PSTN retail price and second with respect to access price regulation. We then conclude by addressing a couple of limitations of our analysis which suggest avenues for further research.

Regulation of the PSTN retail price: The PSTN retail price only affects competition in the VoIP segment as a consequence of the endogenous nature of consumers' technology adoption decisions. An important result of the analysis is that, as long as the PSTN access price is positive, a higher price for PSTN telephony leads to lower prices for VoIP telephony. Only for an access price equal to zero, the retail price level of PSTN telephony does not affect retail prices for VoIP telephony. These results illustrate the links between different telephony networks—links that should not be ignored by regulators. These links have been explored in detail. Suppose that an entrant in the VoIP market faces a positive access price. This access price may or may not reflect marginal cost levels; it is only important that this access price is positive. Then a lower regulated PSTN price leads to a smaller customer base for VoIP telephony and softens price competition among VoIP operators.

Note that if a regulator allows an integrated incumbent to include a mark-up for common costs in its access charge, which is typically the case, then the access price will be above the marginal cost level. The result is less migration to VoIP. Also note that, if a universal service obligation forces the incumbent to price PSTN telephony at a low level, VoIP retail prices become inflated and the adoption of VoIP will be slowed down.

Access regulation: Access regulation on the PSTN network affects the VoIP market. For instance, if the incumbent charges for call termination on the PSTN and VoIP networks use bill-and-keep, then a higher access price for call termination on the PSTN network leads to a smaller customer base for VoIP telephony. In the context of access price regulation it is important that regulators take into account these linkages between different market segments, and that regulation within one segment may have spillover effects to other segments.

In markets in which the PSTN retail price is *not* regulated (and in which an incumbent enjoys market power), a higher access price leads to higher VoIP retail prices (as in the regulated case) but tends to lead to lower retail prices in the PSTN segment. This suggests that regulation has winners and losers: consumers of the "old" technology are the winners from a high access price (which can be seen as a protective measure for the old technology) and consumer of the "new" technology are the losers.

Limitations and avenues for further research: Our modelling strategy has been to isolate the cost effects of access price regulation abstracting from at least two important issues, vertical integration and predation. Recall that vertical integration in our model with a given PSTN price is neutral to competition, that is, retail prices in the VoIP segment are independent of whether or not the PSTN operator is vertically integrated into VoIP. Thus cannibalization is not an issue. This result is due to the particular timing in our model: an integrated firm with a regulated PSTN price cannot commit to a high VoIP price (which would avoid cannibalization).[21] We make three observations related to vertical integration. First, since a lower access price leads to higher retail profits in the VoIP segment, a vertically integrated PSTN incumbent has less incentives to lobby for an increase in the access price than a non-integrated PSTN operator (also, within a cost-based regulatory regime it may have more flexibility to adjust the access price due to some arbitrariness in attributing common costs). Second, the firm can possibly commit not to offer VoIP services at all. If we introduce this possibility in our model, there is a range of parameters where this is indeed the profit maximizing solution for the incumbent. By not offering VoIP services it relaxes competition in the VoIP segment thus making consumers reluctant to migrate to VoIP. Third, if we endogenize the PSTN price, our model no longer has the property that integration is neutral to competition. An integrated firm takes profits from retail in the VoIP segment into account and adjusts the PSTN price accordingly.

Finally, we note that in our model, predation is not an issue. Predation tends to make the incumbent more aggressive in the VoIP market as an attempt to maintain its customer base. Such predatory behavior arises in dynamic models, in particular with consumer switching costs. We leave it for future research to analyze predatory behavior in the context of VoIP.

[21] The cannibalization issue would arise in a model in which consumers make their purchasing decision after observing all prices. The corresponding model is less tractable since market shares are more complicated functions. However we have solved this alternative model numerically. Our qualitative findings that the access price is *not* neutral to the entrant's profits are confirmed in this alternative setting, provided the PSTN retail price is given.

Appendix: Proof of Lemma 1.

The expected utility of a consumer of type t who intends to migrate to VoIP is determined as follows:

$$
\begin{aligned}
&\int_0^{s_1(\widehat{p}_1,\widehat{p}_2)}[r+U_1-\tau t-\theta y-p_1]\mathrm{d}y+\int_{s_1(\widehat{p}_1,\widehat{p}_2)}^{1}[r-\tau t-\theta(1-y)-p_2]\mathrm{d}y\\
&= s_1(\widehat{p}_1,\widehat{p}_2)r+s_1(\widehat{p}_1,\widehat{p}_2)U_1-s_1(\widehat{p}_1,\widehat{p}_2)\tau t-\theta\frac{s_1(\widehat{p}_1,\widehat{p}_2)^2}{2}-s_1(\widehat{p}_1,\widehat{p}_2)\widehat{p}_1\\
&\quad +s_2(\widehat{p}_1,\widehat{p}_2)r-s_2(\widehat{p}_1,\widehat{p}_2)\tau t-\theta\frac{s_2(\widehat{p}_1,\widehat{p}_2)^2}{2}-s_2(\widehat{p}_1,\widehat{p}_2)\widehat{p}_2\\
&= r-\tau t-s_1(\widehat{p}_1,\widehat{p}_2)(\widehat{p}_1-U_1)-s_2(\widehat{p}_1,\widehat{p}_2)\widehat{p}_2-\frac{\theta}{2}[s_1(\widehat{p}_1,\widehat{p}_2)^2+s_2(\widehat{p}_1,\widehat{p}_2)^2]\\
&= r-\tau t-\frac{\theta}{2}\\
&\quad -s_1(\widehat{p}_1,\widehat{p}_2)(\widehat{p}_1-U_1)-s_2(\widehat{p}_1,\widehat{p}_2)\widehat{p}_2-\frac{\theta}{2}[s_1(\widehat{p}_1,\widehat{p}_2)^2+s_2(\widehat{p}_1,\widehat{p}_2)^2-1]\\
&= r-\tau t-\frac{\theta}{2}-\widetilde{p}(\widehat{p}_1,\widehat{p}_2),
\end{aligned}
$$

where

$$
\widetilde{p}(\widehat{p}_1,\widehat{p}_2)\equiv s_1(\widehat{p}_1,\widehat{p}_2)(\widehat{p}_1-U_1)+s_2(\widehat{p}_1,\widehat{p}_2)\widehat{p}_2+\frac{\theta}{2}[s_1(\widehat{p}_1,\widehat{p}_2)^2+s_2(\widehat{p}_1,\widehat{p}_2)^2-1].
$$

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