International University in Germany

School of Business Administration

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Working Paper 43/2006

Bruchsal, May 2006

ISSN 1613-6691 (print version)
ISSN 1613-6705 (online version)

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Access Regulation and the Adoption of VoIP[1]

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31 May 2006

[1]Financial support from ENCORE (Economics Network for Competition and Regulation) is gratefully acknowledged. We would like to thank Georg Götz; the Dutch telecommunications and postal authority OPTA, in particular, Jorn van Steenis and Elbert Jan van Veldhuizen; and seminar participants at OPTA, University of Antwerp, Tilburg University, and the 2006 meeting of the Industrial Economics Section of the Verein für Socialpolitik for helpful comments and discussions. Only the authors are responsible for the contents of this paper and any errors it may contain.

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Abstract

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 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 exclusively VoIP telephony.

JEL-Classification: L96, L51, L13.

Keywords: telecommunications, voice over broadband (VoB), voice over Internet protocol (VoIP), entry, access, regulation, imperfect competition.

1 Introduction

With the emergence of voice telephony based on the Internet protocol, 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 PSTN (public switched telephone network), is providing a new impetus to local loop unbundling (LLU) and also stimulates entry into telephony markets by cable operators. Without even mentioning software applications for voice telephony that run completely over the Internet, it is clear that incumbent operators are facing a serious threat. In particular, they face the question of whether they should milk the PSTN as long as possible, or introduce VoIP quickly and at low prices, at the cost of cannibalizing PSTN revenues, in the hope of at least partially deterring entry of new operators.

In this paper we explore a situation of imperfect competition between an incumbent and an entrant. While the incumbent, with a history in PSTN telephony, is assumed to have 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 (public switched telephone network) 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 distinguish two set-ups. In the first one, the relative size of these segments is exogenously given, so that there is no migration from PSTN to VoIP services. In the second set-up, we allow for endogenous migration between the segments, so that consumers actually choose between staying with the PSTN network versus adopting VoIP services.[1]

In this set-up, we explore the nature of 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 addition, we explicitly focus on the effects of regulation on the market. Accordingly, there is a close link to regulatory practice. National regulatory authorities (NRAs) 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.

[1] In both cases, we assume that there is full coverage, that is, all consumers make a purchase. See De Bijl and Peitz (forthcoming) for an analysis of partial market coverage in a setting that focuses on unbundling rather than terminating access.

In this paper, we mainly focus on regulation of terminating access. We will also discuss the effects that the retail price in the market for PSTN telephony may have on market outcomes in the VoIP segment. Accordingly, we will not so much be considering regulation of the VoIP market itself. Instead, we 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 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).[2] Our aim is to articulate some of the most salient side effects of current regulatory interventions.

The assumption of imperfect competition means that both operators have some market power; such a situation is more realistic than the 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 underlying marginal cost level. We will summarize our results in the concluding section of the paper.

Literature review. 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), De Bijl and Peitz (2002), and Vogelsang (2003). Our paper builds on that literature by analyzing the emergence of VoIP networks in a PSTN environment, and 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 may 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.

Note that technically speaking, we look at a two-way access problem. However, when VoIP operators do not charge for access, our set-up boils down to a one-way access problem. Hence

[2] 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.

our paper directly connects to the literature on one-way access, which has typically focused on access problems in which either all firms or at least the downstream entrants do not have market power in the retail segment. In the former case there is pure Bertrand competition, and in the latter case, downstream entrants form a (perfectly) competitive fringe. In such settings, when the incumbent's retail price is assumed to be fixed, the efficient component pricing rule (ECPR) has been proposed as the socially optimal pricing method for setting the incumbent's access price (see Baumol, 1983, and Willig, 1979). The ECPR says that to obtain productive efficiency, the access price should be equal to the marginal cost of access plus the incumbent's opportunity cost of providing access (the incumbent's lost profits due to entry). If the incumbent and the entrant offer perfect substitutes, this rule reduces to the margin rule according to which the incumbent's lost profit equals its lost retail revenues (Armstrong, 2002). Accordingly, the vertically integrated incumbent can increase its profits by granting access to a more efficient downstream entrant. Since foreclosure is unprofitable if an entrant is more efficient, there is no need to regulate the incumbent's access price. However, the logic behind the ECPR has been challenged in several adaptations and extensions; see Armstrong (2002) for a thorough overview.

Access pricing in a situation of 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 (forthcoming), among others. Laffont and Tirole (1994) analyze the implementation of Ramsey prices via a global price cap. Apparently, imperfect competition complicates the appropriate use of a global price cap, because supply-side and demand-side effects have to be taken into account simultaneously. In a full information world, in which only the access price is regulated, the idea is to replace retail regulation by competition. 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; and Lewis and Sappington, 1999). In addition, in an asymmetric market the regulator may want to use the access price to favor the more efficient firm (Armstrong and Vickers, 1998; Lewis and Sappington, 1999; and De Bijl and Peitz, forthcoming). The reason behind such a policy is that the more efficient firm would otherwise obtain a market share that is less than socially optimal. Note that such a bias becomes less pronounced in a more competitive market (Lewis and Sappington, 1999).

Foros (2004) analyzes a competitive situation which is somewhat related to ours. 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 firms compete in a Cournot fashion in the retail market. 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. Hence, Foros' results can be seen as complementary to ours.

The economics literature has also looked at bypass possibilities (see e.g. Armstrong, Doyle and Vickers, 1996; Laffont and Tirole, 1994, 1996). Note, however, that although VoIP can substitute PSTN telephony, it does not allow for full bypass as long as some consumers stay with the PSTN. In our model, with full penetration of VoIP the access problem has disappeared whereas at any intermediate situation, terminating access to PSTN remains essential and a bypass possibility is not available.

With respect to our modeling framework, this paper also contributes to the literature on multiproduct firms in a multidimensional product space. This literature has been reviewed in Manez and Waterson (2001).[3] In this paper we provide a tractable model of multiproduct competition which allows for endogenous formation of market segments and can be solved analytically. However, our model has the property that integration does not affect the incentives with respect to prices (in the VoIP segment). Our framework may prove to be useful for other applications in industrial organization.

The structure of this paper is as follows. Section 2 provides some illustrative background information on terminating access in relation to VoIP. In section 3, we explore a model in which the group of consumers purchasing VoIP services is exogenously given. Section 4 analyzes the case in which migration from PSTN to VoIP services is endogenously determined. Section 5 concludes the paper and summarizes the results.

2 Terminating access and VoIP in practice

In this section, we provide some background on IP-based services, wholesale access to local access networks, and call termination. Also, based on this background information we clarify the focus of our analysis, as it is beyond the scope of this paper to provide a comprehensive analysis of VoIP. We abstract from LLU regulation in order to focus on regulation of

[3] Contributions include Katz (1984), Lal and Matutes (1989) and Canoy and Peitz (1997).

terminating access.[4]

2.1 IP-based telephony

The Internet Protocol (IP) is a data protocol, based on packet switching rather than circuit switching, that is used for routing and carriage of messages over the Internet. As any type of electronic information can be transported in packets, IP can also be applied to transport voice calls.

The number and variety of IP-based telephony service propositions are large and increasing, and terms like VoIP, IP telephony and Internet telephony are often used interchangeably. In order to clarify the focus of our paper, it is useful to recapitulate the main types of IP-based telephony:

1. *IP-based transport in the core of traditional networks:* At the level of long-distance backbones, PSTN operators have been supplementing and replacing traditional circuit-switched technology with IP-based technology. To reach end-users, they may still use traditional (i.e., not upgraded to DSL) copper wires connections.

2. *IP-based transport at the edges of traditional networks, allowing for IP-based offerings from traditional operators:* PSTN operators may upgrade their local connections to digital subscriber lines (DSL), enabling broadband Internet access.[5] Such connections may also be used to offer VoIP telephony. This type of VoIP is also know as voice over broadband (VoB) or voice over DSL (VoD). Operators may offer Internet access and VoIP services as a bundle.

3. *IP-based offerings from cable operators:* 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. Again, these offerings may be sold as a bundle.

4. *IP-based offerings from entrants without local networks base on LLU:* 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

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

[5] DSL is a technique that increases the available frequency spectrum on copper wires, so that more data can be sent through a line.

end-users. This type of VoIP is also know as voice over broadband (VoB) or voice over DSL (VoD).

5. *IP-based offerings from entrants without local networks based on bitstream access:* Entrants without their own local loops can purchase "bitstream "access from the incumbent or an entrant using the incumbent's unbundled DSL connections, and offer broadband Internet access or VoIP services to end-users.

6. *IP-based offerings through an ISP:* End-users, subscribing to an ISP, may purchase VoIP from or via that ISP.

7. *Fully IP-based "next generation networks":* Operators may roll out new networks or upgrade existing ones to create completely IP-based networks. An example is BT's 21st Century Network.

8. *VoIP over the Internet:* This is IP-based telephony that is purely Internet-based. Consumers with Internet access can download free, peer–to-peer based, voice telephony software, enabling them to make free calls to consumers with the same software installed on their computers (computer-to-computer calls). A well-known example of this software is Skype. Calls to subscribers of other telecoms networks (computer-to-phone calls) are also possible, although they may be charged, as termination on other networks may be costly.

9. *IP-based private branch exchanges (PBXs):* Corporate customers may, for in-house telecommunications services on their local and wireless access networks (LAN and WAN), use IP-enabled switches. Traditionally, in-house switches were circuit-switched. Note that with an IP-PBX, calls to the outside world may be transformed into circuit-switched calls, depending on the nature of the network that a customer subscribes to.

Experts expect that the current variety will remain for the foreseeable future, if only because of the wide diversity in the ways that end-users have access to services.[6]

In this paper, we restrict our focus to competition between an incumbent offering IP-based services (type 2 or 7) and an entrant with or without a local network (type 3, 4 or 5). Note that for type 7 (the incumbent upgrading to a next generation network), we assume in our analysis that it is still in the process of upgrading its network from a PSTN to an all-IP

[6] Ofcom (2006, p. 8-9).

network, so that during this transition, it offers both PSTN and IP-based telephony. In case of a LLU-based entrant (type 4), we abstract from problems associated with the setting of the wholesale lease price of local loops. In our analysis, 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. Finally note that in our models, we implicitly allow for IP-based backbones (type 1), as we do not specify the nature of long-distance backbones.

2.2 Terminating access

Public telecoms networks, whether PSTN or IP-based, must interconnect with one another, so that users can be reached irrespective of the network that they subscribe to. The process that makes this possible, network interconnection, consists of the mutual provision of terminating access. Traditionally, operators charge each other for call termination. Charging for call termination is typically done on a per-minute basis. An alternative to charging for access is "bill-and-keep" (or "reciprocal settlement-free termination"), a system in which calls are terminated without access payments between operators. The emergence of VoIP may radically change operators' wholesale deals on call termination.[7]

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 charges. Accordingly, for calls from an IP-network to a PSTN, a VoIP provider may have to pay for call termination. Such charges create a perceived marginal cost for the VoIP provider, which possibly translates into a strictly positive per-minute price for this type of call. In the case of calls from one IP-based network to another, operators may find it more efficient to implement bill-and-keep, in line with the packet-based nature of VoIP that, to a certain extent, eliminates the logic of metering incoming calls.

In the basis case of our analysis, we suppose that the incumbent charges for call termina-

[7] See Analysys (2004) for an overview of possible business models for call termination.

tion on its PSTN, and that no termination charges are used for other types of calls. This is in line with the observation that the marginal cost for termination at the PSTN is typically seen as being strictly positive, whereas call termination on IP-based networks comes virtually without a cost. It is straightforward to consider different wholesale pricing schemes in our models, though.[8]

3 Exogenously given consumer segments

3.1 The model

There are two firms, an incumbent (operator 1) and an entrant (operator 2). The incumbent is assumed to have a complete local access network. The incumbent's network 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 footing as the incumbent. This assumption allows us to abstract from regulatory issues that stem from LLU, and focus solely on terminating access.

Consumers are heterogeneous with respect to their reluctance to use a new rather than an established technology (with some abuse of language, we will sometimes refer to consumer groups as "old" and "new" segments). 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. 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. A possible interpretation is that consumers in the old segment are narrowband users, whereas consumers in the new segment are broadband users.

[8] 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."

Throughout this section, we assume that consumers cannot "migrate" from one segment to the other, while the segment sizes are exogenously given (this assumption will be dropped in the subsequent section).

All networks are interconnected, so that any consumer can make calls to any other consumer. To allow for a call from one operator's network to the other's network, the first operator must purchase a wholesale service called "terminating access" from the second one. We assume that the marginal cost of call termination on a VoIP network is 0,[9] and that operators do not charge for call termination to a customer subscribing to a VoIP service. 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. 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. To keep the number of parameters small without loss of generality, we set all other costs equal to zero.

Access price a is set by a regulator.[10] Since we do not explicitly model the regulator as a player, access price a is an exogenous parameter in our model.

By supposing that all consumers have an identical, inelastic demand to make calls once they have a subscription, each consumer will make a given number of calls. Without loss of generality, we normalize this number to 1.[11]

The retail price in the old segment is assumed to be given by p_0. 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).[12] 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, $i = 1, 2$. Note that implicitly, all per-minute

[9] 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.

[10] For instance, the regulator has determined that the incumbent has "significant market power "(SMP) 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 EU member states).

[11] See De Bijl and Peitz (2002) for a more elaborate specification.

[12] 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.

prices are 0.

In a more elaborate model, one could incorporate that consumers have elastic demand to make calls, or to have access to the Internet, in addition to the demand for a subscription. Such extensions lead to additional interactions between the operators, for instance because there is call traffic between the networks—see De Bijl and Peitz (2002) for an inclusion of call traffic. Nevertheless, the present model is rich enough to capture some crucial elements of the strategic interaction between PSTN and VoIP providers.[13]

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. This implies that calling patterns are balanced, that is, the volumes of on-net and off-net calls are proportionate to market shares. This assumption, which is common in the literature on competition in telecommunications markets, simplifies the analysis and should be seen as the natural benchmark.

Market shares in the segment of the new technology depend on the retail prices, and are denoted by $s_i(p_1, p_2)$, $i = 1, 2$. We assume that an operator's market share is decreasing in its own price and increasing in the price of its rival. Furthermore, we assume that market shares only depend on the price difference $p_2 - p_1$. This assumption is satisfied for quasi-linear preferences when consumers have identical demand functions. With full participation, total market demand is fixed. For an example see below. Figure 1 illustrates the set-up of the model.

The property that market share changes continuously with price implies that firms have market power. Consumers do not consider the services provided by the two firms as perfect substitutes and therefore do not necessarily go for the lowest price. In reality, imperfect substitutes seem 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.

[13]the present model may be seen as an approximation of a model with positive usage charges but rather inelastic demand. The demand assumptions simplify the analysis considerably and allows us to focus on participation decisions, abstracting from usage intensity. In the light of the enormous variety in non-linear contracts, the case of flat fees in a world of "simple"demand structures provides a natural benchmark. Traditionally, operators have set two-part tariffs for PSTN telephony, while at present, operators seem to be inclined to set flat fees for VoIP services (possibly combined with linear prices for calls terminating on the PSTN). Related to the emergence of IP-based telephony, there seems to be a trend towards flat fees for all voice telephony services.

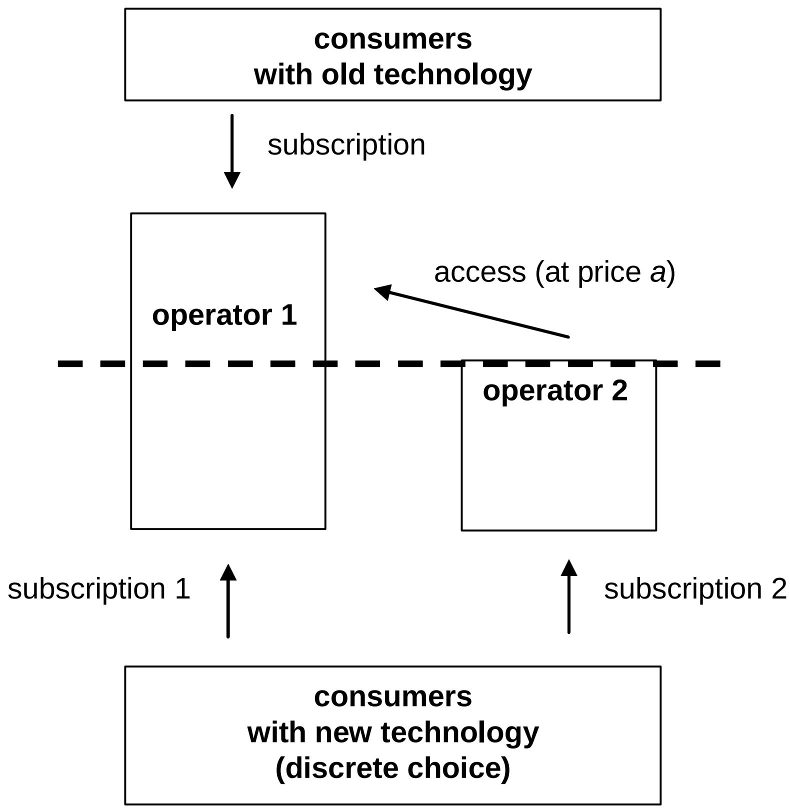

Figure 1: Illustration of the model.

Profit functions are as follows. Firm 1's profits can be written as

$$\pi_1(p_1, p_2; a, p_0) = \lambda_0[p_0 - \lambda_0 c] + \lambda[s_1(p_1, p_2)(p_1 - \lambda_0 c) + s_2(p_1, p_2)\lambda_0(a - c)], \qquad (1)$$

and firm 2's profits as

$$\pi_2(p_1, p_2; a) = \lambda s_2(p_1, p_2)(p_2 - \lambda_0 a). \qquad (2)$$

These profit functions 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.

A special case of our general model is obtained by assuming that the networks are horizontally differentiated. Suppose, for instance, that consumers are uniformly distributed on the interval $[0, 1]$. Firm 1 is located at location $y_1 = 0$ on the interval, and firm 2 at $y_2 = 1$. A consumer located at z buying from firm i incurs a disutility $-\theta|y_i - z|$. Note that a higher value of parameter θ corresponds to more differentiation between the networks. A consumer at z buys from firm 1 if $v_1(p_1, p_2) - \theta z > v_2(p_1, p_2) - \theta(1 - z)$, where $v_i(p_1, p_2)$ denotes the conditional indirect utility of a network at the ideal location z. Market shares then satisfy $s_i(p_1, p_2) = \frac{1}{2} + (v_i(p_1, p_2) - v_j(p_1, p_2))/(2\theta)$, where $j \neq i$. This is a simple Hotelling specification which has also been widely used in models on two-way access (see e.g. Laffont, Rey and Tirole, 1998; Armstrong, 1998; and the survey by Armstrong, 2002).

Structure of the game and equilibrium: The structure of the model is as follows:
$t = 0$: The regulator sets access price a and retail price p_0, or alternatively, the latter price is determined by a competitive fringe in the retail price for PSTN voice telephony.
$t = 1$: Operators choose their prices for VoIP voice services in order to maximize profits.
$t = 2$: Consumers observe retail prices and make purchasing decisions, based on utility maximization. Consequently, market shares and profit levels are realized.

We are interested in a Nash equilibrium in prices (p_1^*, p_2^*), which is defined in such a way that given its rival price, neither firm has an incentive to change its own price. That is, each operator's price p_i^* maximizes profits $\pi_i(p_1, p_2; a, p_0)$ when p_j^* is given, $i \neq j$. Accordingly, given the equilibrium price of the competitor, the profit maximization problem of operator 1 can be written as

$$\max_{p_1} \pi_1(p_1, p_2^*; a, p_0), \tag{3}$$

while operator 2 maximizes

$$\max_{p_2} \pi_2(p_1^*, p_2; a, p_0). \tag{4}$$

3.2 Analysis

Suppose that there exists a unique pair (p_1^*, p_2^*) which solves problems (3) and (4) simultaneously (hence it constitutes an equilibrium). We are then interested in which way a change in regulatory policy with regard to the access price a affects market outcomes. Hence, consider the following increase of the termination charge: $a' = a + \Delta a$, where $\Delta a > 0$. We can then show that this increase is passed through to consumers. Market shares in equilibrium, as well as the entrant's profits, are unaffected. However, we will see that the incumbent benefits in two ways: (i) it can charge a higher mark-up in the retail market, and (ii) it receives higher revenues from calls that terminate on its PSTN network. Consumers in the new segment are worse off, as the they face higher retail prices by both networks. We will now explore the underlying mechanism in detail.

Given the new access price a', we claim that equilibrium retail prices are $p_1^{**} = p_1^* + \lambda_0 \Delta a$ and $p_2^{**} = p_2^* + \lambda_0 \Delta a$. Our proof consists of establishing that for each operator i, p_i^{**} is the solution of the maximization problem of operator i.

Operator 1: Given the new access price a', the incumbent's profit can be written as

$$\pi_1(p_1, p_2; a', p_0) = \lambda_0(p_0 - \lambda_0 c) + \lambda[s_1(p_1, p_2^{**})(p_1 - \lambda_0 c) + (1 - s_1(p_1, p_2^{**}))\lambda_0(a + \Delta a - c).$$

Provided that the competing operator sets $p_2^{**} = p_2^* + \lambda_0 \Delta a$, the incumbent's market share satisfies $s_1(p_1, p_2^{**}) = s_1(p_1 - \lambda_0 \Delta a, p_2^*)$ because they only depend on price differences. Hence operator 1's profit can be rewritten as

$$\lambda_0(p_0 - \lambda_0 c) + \lambda[s_1(p_1 - \lambda_0 \Delta a, p_2^*)(p_1 - \lambda_0 \Delta a - \lambda_0 c) + \lambda_0(1 - s_1(p_1 - \lambda_0 \Delta a, p_2^*))(a - c) + \lambda_0 \Delta a].$$

With a change of variable $\widetilde{p}_1 \equiv p_1 - \lambda_0 \Delta a$, the incumbent's maximization problem becomes

$$\max_{\widetilde{p}_1} \lambda_0(p_0 - \lambda_0 c) + \lambda[s_1(\widetilde{p}_1, p_2^*)(\widetilde{p}_1 - \lambda_0 c) + \lambda_0(1 - s_1(\widetilde{p}_1, p_2^*))(a - c)] + \lambda\lambda_0 \Delta a \tag{5}$$

Clearly, p_1^* is the solution to this problem because, apart from the constant $\lambda\lambda_0\Delta a$, it is exactly the same as problem (3). Since $\widetilde{p}_1 \equiv p_1 - \lambda_0 \Delta a$ we have shown that $p_1^{**} = p_1^* + \lambda_0 \Delta a$, provided that $p_2^{**} = p_2^* + \lambda_0 \Delta a$. Moreover, notice that the increase in the access price leads to an increase in the incumbent's profits by $\lambda\lambda_0\Delta a$.

Operator 2: Given the new access charge a', operator 2's profit can be written as

$$\pi_2(p_1, p_2; a') = \lambda s_2(p_1^{**}, p_2)(p_2 - \lambda_0(a + \Delta a))$$

Provided that the competing operator sets $p_1^{**} = p_1^* + \lambda_0 \Delta a$, the entrant's market share satisfies $s_2(p_1^{**}, p_2) = s_2(p_1^*, p_2 - \lambda_0 \Delta a)$. Hence, using the change of variable $\widetilde{p}_2 = p_2 - \lambda_0 \Delta a$ the maximization problem of the non-integrated network's profit can be written as

$$\max_{\widetilde{p}_2} s_2(p_1^*, \widetilde{p}_2)(\widetilde{p}_2 - \lambda_0 a) \tag{6}$$

Clearly, p_2^* is the solution to this problem because it is equivalent to problem (4). Since $\widetilde{p}_2 \equiv p_2 - \lambda_0 \Delta a$ we have shown that $p_2^{**} = p_2^* + \lambda_0 \Delta a$, provided that $p_1^{**} = p_1^* + \lambda_0 \Delta a$.

Hence, we have established the following result:

Result 3.1. *Consider an increase in access price for call termination on the PSTN network. As a consequence, the incumbent's profits increase, while the entrant's profits are unaffected.*

Both operators pass on the access price increase to consumers by charging a higher retail price for VoIP telephony. Market shares remain the same.

The result says that rents are redistributed from consumers using the new technology to the bottleneck owner of the old technology. It is instructive to take another look at the above result. An access price increase by Δa works affects prices in the same way as a per-user cost increase of the new technology (of magnitude $\lambda_0 \Delta a$). This can be seen as follows. The profits of operator 2 are equal to $\lambda s_2(p_1, p_2)(p_2 - \lambda_0 a + \lambda_0 \Delta a)$, that is, the profit function has the same form as with access price a and costs $\lambda_0 \Delta a$. The profit function of operator 1 becomes

$$\pi_1(p_1, p_2; a + \Delta a, p_0) = \lambda_0(p_0 - c) + \lambda[s_1(p_1, p_2^{**})p_1 + \lambda_0(1 - s_1(p_1, p_2^{**}))(a + \Delta a) - \lambda_0 c].$$

The profit-maximizing price p_1 when p_2 is given, is determined by the first-order condition of profit maximization:

$$\frac{\partial s_1(p_1, p_2)}{\partial p_1} p_1 - \lambda_0 \frac{\partial s_1(p_1, p_2)}{\partial p_1}(a + \Delta a) + s_1(p_1, p_2) = 0,$$

which is equivalent to

$$\frac{\partial s_1(p_1, p_2)}{\partial p_1}(p_1 - \lambda_0 \Delta a) - \lambda_0 \frac{\partial s_1(p_1, p_2)}{\partial p_1} a + s_1(p_1, p_2) = 0.$$

This equation is also the first-order condition of profit maximization given access price a and per-used costs $\lambda_0 \Delta a$ for the new technology. Hence, a access price increase for accessing the old technology is passed on to consumers (which increases the expected cost of providing service for firm 2 by $\lambda_0 \Delta a$) in exactly the same way as a cost increase for a the new technology by $\lambda_0 \Delta a$. The only difference between an access price increase and a cost increase is that the owner of the essential facility, that is, firm 1, benefits from an access price increase because the associated "downstream" cost increase generates revenues "upstream" at the essential facility. All consumers using the new technology suffer. In terms of consumer behavior this suggests that providing an access rule that is beneficial to the network owner of the old technology is likely to discourage consumers to move to the new technology. We will return to this issue when we analyze a model with endogenous consumer migration.

While a high access price is not desirable for consumers, firm 2's after entry profits are neutral with respect to the access price. Hence, in this simple model, entry incentives are not affected by the level of the access price. However, for high retail prices (which are due to a high access price), at some point the participation or incentive constraint becomes binding (for some consumers). When that happens, there is no full pass-through of access payments to the consumers of firm 2. Rather firm 2 will have to reduce its profit margin, making entry less attractive. See also the next section, which explicitly considers the incentive constraint of consumers to adopt the new technology.

In the present context an analysis of total surplus is straightforward. Provided that the market is symmetric, the socially desirable market share for each operator is 50%. This is an equilibrium outcome for any access price such that the participation constraint of consumers is not violated (and the technology choice by consumers is exogenous). However, if the market is not fully symmetric, strategic behavior between firms typically does not lead to an implementation of a socially optimal outcome. In particular, if one network is more attractive than the other on average, then the equilibrium market share of the less attractive network is socially excessive.[14]

4 Consumers choosing between PSTN and VoIP

4.1 The model

In the previous section, we assumed that a fraction of λ_0 consumers stay with the PSTN-based technology, while the remaining fraction of consumers λ adopt VoIP; these fractions were exogenously given ($\lambda_0 + \lambda = 1$). In this section we look at the case in which consumers can decide to switch from PSTN to VoIP. If they do so, they can choose between the VoIP offerings of the incumbent and the entrant.

As before, the marginal cost of call termination on the PSTN network is $c > 0$, while the incumbent charges a termination charge a for call termination to its PSTN customers. Consumers have identical, inelastic demand for one unit of telephony services, while calling patterns are balanced. Market shares in VoIP services are denoted by $s_i(p_1, p_2)$, $i = 1, 2$. We extend on our earlier model specification as follows.

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

[14]However, in difference to Armstrong and Vickers (1998) and Lewis and Sappington (1999), the access price does not affect market shares and therefore is ineffective. See also the model in the following section.

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 purchase PSTN or VoIP services.[15]

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 $U_1 \in \mathbb{R}$ can be interpreted as a brand or firm-specific utility that captures the asymmetry between operators. Similarly, a consumer who purchases VoIP services from firm 2 derives utility $r - \tau t - \theta(1 - y) - p_2$. We will implicitly assume that all consumers make a purchase; hence, parameters are such that there is always a technology available that delivers sufficient gross utility.

Fulfilled expectations: We will be assuming that before consumers learn the prices of VoIP services, they have certain beliefs about the prices that they can expect, and based on these beliefs, they figure out whether to go for VoIP or stick with PSTN. This may correspond to a situation in which consumers—before they actively start searching for information about a recently introduced product that they are interested in—have already had some exposure to some information about that good, for instance through friends and relatives, articles in newspapers and magazines, and advertisements that they may have passively observed. Hence they are aware of the existence of the product, and, based on the various pieces of information that they have received, they form expectations about its price. Now suppose that based on her beliefs and preferences, a consumer decides that she wants to buy VoIP services. She

[15] This does not affect our results in any important way.

will then start searching more actively, in order to learn actual prices. Also, she will make comparison between the incumbent's virtues compared to those of the competitor. We may allow for consumers to return to PSTN if they find out that VoIP is too expensive compared to its benefits. However, if beliefs concerning prices are correct, this will not happen. In our model, we do not explicitly incorporate underlying processes of advertising, belief formation and search behavior, but we capture the essence by requiring that in equilibrium, beliefs must be fulfilled. Accordingly, consumers make their migration decision, that is, whether or not to adopt VoIP, *before* VoIP prices are searched.[16]

An alternative way of understanding this specification is to argue that the decision to migrate to VoIP involves a certain level of commitment, as the effort to make a first comparison between PSTN and VoIP services has been sunk (and possibly some equipment has been replaced), whereas prices can be adjusted in a more flexible way. In other words, due to search and learning costs, consumer migration to the new technology involves more commitment than setting prices.[17]

Consumers have identical beliefs about VoIP prices. Moreover, since we restrict the analysis to pure strategies, a belief function can be described by a function that, for each firm i, attaches probability 1 to one particular price level $\widehat{p}_i$, and probability 0 to all other prices $p_i \neq \widehat{p}_i$. To simplify the notation, we will not explicitly define these belief functions, but more simply summarize beliefs by $\widehat{p}_1$ and $\widehat{p}_2$.

Profit functions: The profit functions have the same structure as specified in the previous section. Because of endogenous consumer migration, they have to be adapted as follows:

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

Structure of the game and equilibrium: The model that we analyze then has the following

[16] Another possibility would be that consumers decide after observing prices *and* their taste parameters. While we consider such a specification a valid alternative, such a model becomes very cumbersome to work with.

[17] An alternative specification would be to assume that consumers do have price information before making their migration decision (but do not yet know their taste parameter with respect to operators). This would give the entrant more possibilities to penetrate the market with its VoIP services and would introduce an additional strategic dimension into the problem. Namely, the incumbent could make the VoIP segment on average less attractive by increasing its price.

structure:

$t = 0$: The regulator sets access price a and PSTN price p_0, observed by all.[18]

$t = 1$: 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 decide whether to go for PSTN or 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.

We solve for fulfilled expectation equilibrium, that is, (i) each firm maximizes its profits while taking consumers' beliefs and its rival's strategy as given; (ii) based on their beliefs $\widehat{p}_1$, $\widehat{p}_2$ consumers choose the utility maximizing technology. Subsequently, at stage 2, given the prices set by the firms, they choose the utility maximizing operator provided they adopted the new technology; and (iii) in equilibrium, consumers' beliefs are fulfilled, so that equilibrium prices p_1^* and p_2^* satisfy $p_1^* = \widehat{p}_1$ and $p_2^* = \widehat{p}_2$.[19]

Alternative representation. It is important to note that the set-up with fulfilled beliefs is not necessary to keep the model tractable. We would obtain the same results if we solved for subgame perfect equilibria in the game in which stage $t = 2$ is split into two separate stages:

$t = 2a$: Given their preferences consumers decide simultaneously whether to go for PSTN or VoIP.

$t = 2b$: The operators (simultaneously) set VoIP prices p_1 and p_2.

In this alternative formulation, one does not need to introduce consumer beliefs about VoIP prices. At stage 2, consumers maximize their utility given the decision of all other consumers. At this stage consumers' utility levels depend indirectly on the decision of the other consumers, because these subsequently determine the equilibrium prices that are charged.

[18] In an extension of the game, we will later consider the case in which the incumbent chooses the price for the PSTN service.

[19] In their seminal paper Katz and Shapiro (1984) solve for fulfilled expectations equilibria in a market with network effects.

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:

$$\begin{aligned} CS^{\mathrm{PSTN}} &= \int_{\lambda^*}^{1}\int_{0}^{1}(r+U_0-\tau(1-t)-\theta y-p_0)\mathrm{d}y\mathrm{d}t \\ &= [(r+U_0-\tau-p_0-\frac{1}{2}\theta)(1-\lambda^*)+\frac{1}{2}\tau(1-(\lambda^*)^2)]. \end{aligned}$$

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

$$\begin{aligned} CS_1^{\mathrm{VoIP}} &= \int_{0}^{\lambda^*}\int_{0}^{s_1(p_1^*,p_2^*)}(r+U_1-\tau t-\theta y-p_1^*)\mathrm{d}y\mathrm{d}t \\ &= [(r+U_1-p_1^*)s_1(p_1^*,p_2^*)-\frac{1}{2}\theta s_1(p_1^*,p_2^*)^2]\lambda^*-\frac{1}{2}\tau s_1(p_1^*,p_2^*)(\lambda^*)^2. \end{aligned}$$

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

$$\begin{aligned} CS_2^{\mathrm{VoIP}} &= \int_{0}^{\lambda^*}\int_{s_1(p_1^*,p_2^*)}^{1}(r-\tau t-\theta(1-y)-p_2^*)\mathrm{d}y\mathrm{d}t \\ &= [(r-\theta-p_2^*)(1-s_1(p_1^*,p_2^*))+\frac{1}{2}\theta(1-s_1(p_1^*,p_2^*)^2)]\lambda^*-\frac{1}{2}\tau(1-s_1(p_1^*,p_2^*))(\lambda^*)^2 \\ &= [(r-p_2^*)s_2(p_1^*,p_2^*)-\frac{1}{2}\theta s_2(p_1^*,p_2^*)^2]\lambda^*-\frac{1}{2}\tau s_2(p_1^*,p_2^*)(\lambda^*)^2. \end{aligned}$$

Let $CS^{\mathrm{VoIP}} = CS_1^{\mathrm{VoIP}} + CS_2^{\mathrm{VoIP}}$ Aggregate consumer surplus is equal to $CS = CS^{\mathrm{PSTN}} + CS_1^{\mathrm{VoIP}} + CS_2^{\mathrm{VoIP}}$. Producer surplus is equal to aggregate profits: $PS = \pi_1^* + \pi_2^*$. Welfare is then defined as the sum of consumer and producer surplus: $W = CS + PS$.

4.2 Equilibrium analysis

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 $\overline{y}$, given by $U_1 - \theta\overline{y} - p_1 = -\theta(1-\overline{y}) - p_2$. All consumers characterized by parameter $y < \overline{y}$ 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. Hence, the expected utility of a consumer of type t who intends to migrate to VoIP is as follows:

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

where

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

This 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

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

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

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

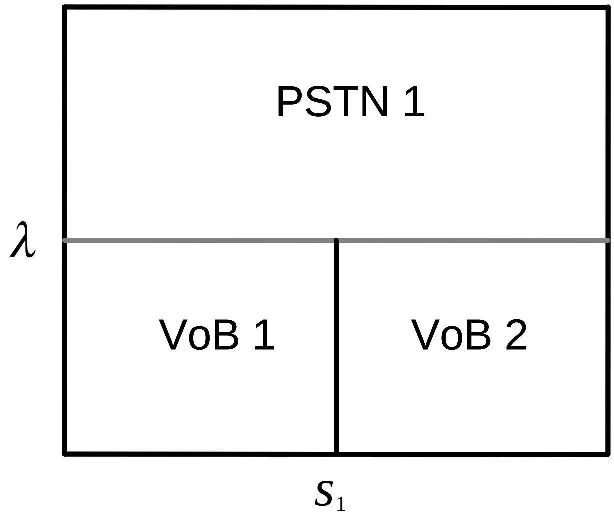

Figure 2: Segments and market shares for PSTN and VoIP telephony.

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

Figure 2 illustrates the endogenous segmentation of the market, and the division of the VoIP segment among the incumbent and the entrant.

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. This simplifies the profit functions. 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. Thus we write $\widetilde{p} = \widetilde{p}(\widehat{p}_1, \widehat{p}_2)$, and 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:

$$p_1(p_0, \widetilde{p}) = \frac{3\theta + U_1}{3} + \frac{a}{2} + \frac{\widetilde{p} - p_0 + U_0}{2\tau} a, \tag{7}$$

$$p_2(p_0, \widetilde{p}) = \frac{3\theta - U_1}{3} + \frac{a}{2} + \frac{\widetilde{p} - p_0 + U_0}{2\tau} a. \tag{8}$$

Some interim observations can be made from equations (7)-(8) 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 given expectations the neutrality result, which was derived in the previous section, still holds. For given expectations, the present model is a special case of the model analyzed in the previous section.

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.

The prices in (7)-(8) do not yet characterize an equilibrium outcome. To be an equilibrium, beliefs must be confirmed in equilibrium, that is, the above solution must satisfy $p_1(p_0, \widetilde{p}) = \widehat{p}_1$ and $p_2(p_0, \widetilde{p}) = \widehat{p}_2$. If we define

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

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

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

The interpretation of this solution is that the quality-adjusted average price for VoIP services is decreasing in the utility of firm 1's VoIP services U_1 (for θ not too small). For $a > 0$, it is increasing in the utility of PSTN services U_0, and decreasing in the price of the competitive segment 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. This is a reasonable restriction in the light of the fact that the underlying marginal costs of call termination are very small or even negligible in reality.

Assumption: $a < 2\tau$.

Substituting the constant $\widetilde{p}^*$ into (7)-(8), we obtain the equilibrium size of the PSTN segment:

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

Next, we obtain equilibrium prices for VoIP services:

$$\begin{aligned} p_1^* &= \theta + \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 30\theta U_1 - U_1^2\} + 24\theta(3\theta + U_1)\tau}{36\theta(2\tau - a)}, \end{aligned} \tag{10}$$

$$\begin{aligned} p_2^* &= \theta - \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 6\theta U_1 - U_1^2\} + 24\theta(3\theta - U_1)\tau}{36\theta(2\tau - a)}. \end{aligned} \tag{11}$$

Note that if an equilibrium exists, it is unique (given by (10)-(11)). One can check that in order for p_1^* and p_2^* to be profit-maximizing prices, the following second-order condition for profit maximization 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 will therefore always be satisfied in an interior equilibrium outcome.[20] Using that $a < 2\tau$, it can be rewritten as $a < \frac{1}{36\theta}U_1^2 + \frac{1}{2}U_1 + p_0 - U_0 - \frac{3}{4}\theta + \tau$.

The insight from the previous section with respect to prices in the VoIP segment is still valid. In the Hotelling specification we obtain the markup due to product differentiation θ corrected by a term that reflects the asymmetry that is introduced due to U_1 plus the marginal cost for operator 2 due to termination on the PSTN segment.

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.

[20] In what follows, we implicitly assume that the solution to the system of first-order conditions for profit maximization characterizes the equilibrium outcome that we discuss.

Remark: Since we are interested in the migration from PSTN to VoIP we analyze only interior equilibria. Here we 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 $r + U_0 - \theta/2 - p_0 < r - \tau - ((s_1^{*0})^2 + (s_2^{*0})^2)\theta/2 + s_1^{*0}(U_1 - p_1^{*0}) - s_2^{*0} p_2^{*0}$.

4.3 Comparative statics

4.3.1 The PSTN terminating access price

The focus of this paper is to understand the impact of regulatory decisions in the PSTN segment on market outcomes in the VoIP segment. For this we derive comparative statics results in the regulated access price a. 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 retail prices are inflated.[21] In the previous section, we showed that the neutrality of firm 2's profits resulted from the property that both firms' equilibrium prices increase by the increase in opportunity costs due to a higher a. This cost increase (compared to the case $a = 0$) is equal to $\lambda_0 a$, which is the expected access payment incurred by the entrant. Since $p_1 - p_2$ was not affected if a increased, market shares s_i remained the same. Note that, in the present model with endogenous segment size, 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,

[21] 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, VoB prices are indeed strategic complements.

that is $\partial\lambda_0^*/\partial a > 0$.[22] Formally, taking derivatives of the expressions reported in equations (10) and (11), we obtain for $i = 1, 2$,

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

Note also that prices respond more strongly to changes in the access price if the access price is already high. Formally, 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

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

Our main comparative statics result can be summarized as follows.

Result 4.1. *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.
(ii) higher prices for VoIP telephony, and
(iii) lower profits for operator 2.

This result not only holds for our particular specification but more generally. Consider profit functions as in equations (1) and (2) that depend on p_i, λ and α. The required properties are that (P1) for given a and λ, prices are strategic complements; (P2) for given λ, a higher access prices increases marginal profits; and (P3) higher retail prices lead to a lower penetration of VoIP. Properties (P1) and (P2) have been shown in the model with exogenous shares λ_0 and λ. Thus, for given λ_0 and λ an increase in a leads to higher prices. Since this is anticipated, given these higher prices more consumers stay with PSTN. This feeds back into higher expected costs for operator 2 and marks a new round in which firms increase their price. Hence, in equilibrium (provided that it exists), prices increase and the market penetration of VoIP decreases.

[22] From equation (9) it can be directly seen that indeed $\partial\lambda_0/\partial a > 0$ whenever $\lambda_0 > 0$.

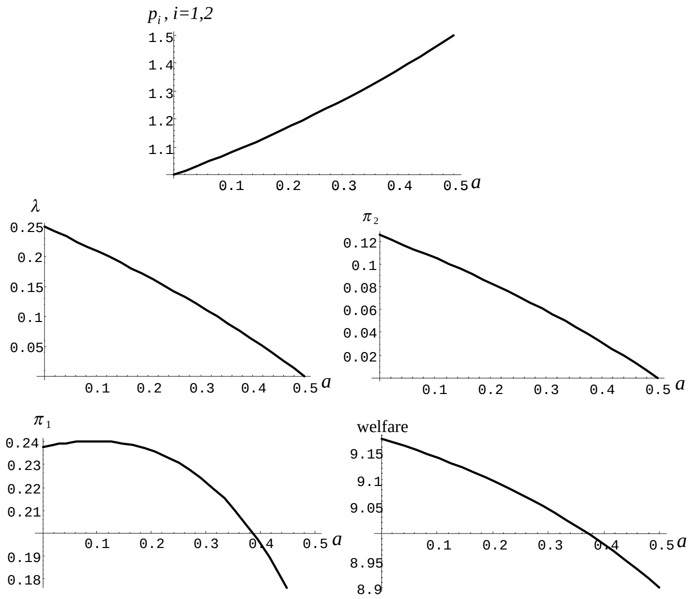

Figure 3: Illustration of the equilibrium outcome when the PSTN retail price is exogenously given.

We will illustrate the equilibrium properties with some diagrams based on a numerical example.[23] 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 $a \in [0, 0.5]$.[24] Figure 3 contains various illustrations of the equilibrium properties.

As illustrated in figure 3, 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. 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

[23] Obtained by using *Mathematica* software.

[24] We have checked the robustness of the effects on surplus levels by varying parameter levels. This confirmed that qualitatively, the observations discussed above do not seem to depend on the parameter levels (within reasonable bounds).

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. 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 shows that total welfare is decreasing in a, which is somewhat surprising as the policy implication is that a should be lower than marginal cost. However, note that we assumed that the demand for calls is perfectly inelastic. This implies that retail prices above or below perceived marginal costs do not affect participation. This, in turn, implies that all welfare results are completely 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 $a \geq 0$). 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.

4.3.2 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 (10)-(11):

Result 4.2.
(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.

Let us discuss these observations in some more detail. 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.

We remark that 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. In principle, the regulator can refrain from regulating the retail price p_0 in the PSTN segment even if, as in our model, firm 1 maintains a monopoly position in that segment. 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. This confirms that VoIP offers by firm 2 give rise to some disciplining effect on the firm 1's PSTN offers. We will return to this situation below.

4.4 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.

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.[25] The calls that the competitive fringe of PSTN entrants without local networks generate, terminate either on the incumbent's PSTN network, or on one of the VoIP networks. Hence each of these entrants faces a perceived marginal cost of $\lambda_0 a + a_0$. Perfect competition in the PSTN retail segment then drives down the incumbent's retail price to $p_0 = \lambda_0 a + a_0$.

In the model, the determination of p_0 takes place as follows. For given access prices, equilibrium prices p_1^* and p_2^* have been determined. Then p_0 is obtained as the fixed point

[25] See also De Bijl and Peitz (2002), ch. 5.

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. The reason is that at the moment they choose VoIP prices, consumers already have made the decision whether to migrate to VoIP or not.

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 the model in section 3, where we assumed that there was no migration between technologies (but distributional effects are typically different).

Sequential price setting: As an alternative to a situation of resale competition in the PSTN segment, 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. In particular, we assume that operator 1 chooses p_0 after all parameters, including the access price, 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. This sequential timing of moves can be motivated by the fact that the incumbent is less flexible in setting PSTN prices than in setting VoIP prices. For instance, because of universal service obligations, the incumbent may have to notify the regulator, or will need regulatory approval, for changes in PSTN prices.

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, so that finding the profit-maximizing PSTN price is relatively straightforward. It can be shown that

$$\begin{aligned} p_0^* &= \frac{1}{144\tau\theta}[36a^2\theta - 3a(U_1^2 + 10U_1\theta - 3\theta(-4c + 4U_0 + \theta - 4\tau)) \\ &\quad +2\tau(U_1^2 - 6U_1\theta + 9\theta(4c + 4U_0 + 5\theta + 4\tau))]. \end{aligned}$$

The following result, which we state without proof, confirms our Result 4.1 for the case that the PSTN retail price is not fixed:

Result 4.3. *For endogenous p_0, a higher access price for call termination on the PSTN network leads to*

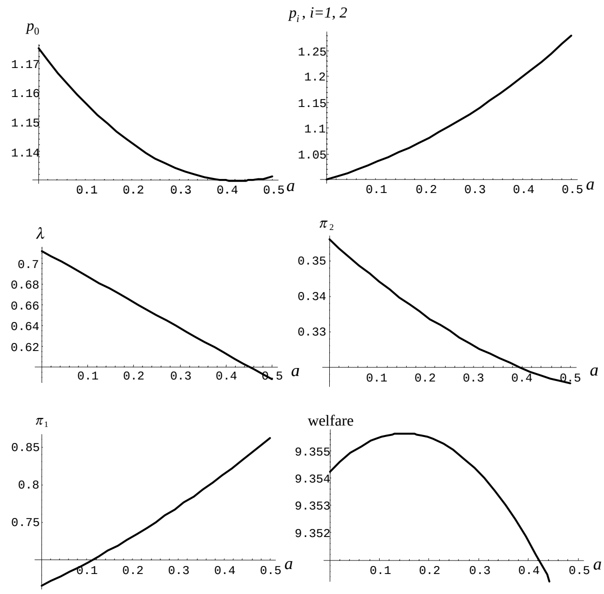

Figure 4: Illustration of the equilibrium outcome when the PSTN retail price is endogenously determined.

(i) a smaller customer base for VoIP telephony.
(ii) higher prices for VoIP telephony, and
(iii) lower profits for operator 2.

We illustrate the equilibrium properties with some diagrams based on numerical calculation, when $\theta = \tau = 1$, $r = 10$, $U_0 = U_1 = 0$, and $c = 0.1$.[26] See figure 4. The PSTN price p_0^* may be decreasing or increasing in access price a. For the chosen parameter values, it is convex in a: first decreasing, but increasing for relatively high values of a.

The observation that $p_0^*(a)$ is U-shaped can be explained as follows. Note that 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. First, recall that earlier we saw that an increase in the access price (for given p_0) led to higher prices in the VoIP segment. This implies that for a given p_0, a higher access price leads to a smaller VoIP segment. However, the incumbent is free to adjust its price. Note that for low levels of the access price, 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

[26] Again obtained by using *Mathematica* software.

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.[27]

Figure 4 shows that total welfare is concave in a. To understand this, recall 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.[28] The regulator could in theory use the access price to implement the optimal split between the PSTN and VoB segment, which explains why the optimal access price is, in general, not equal to marginal cost. The optimal split depends on the parameters of the model. With the parameters of our numerical example the welfare-maximizing allocation does not have the property that $\lambda = 1/2$ for two reasons. First, the PSTN segment is more costly to operate, and second, since there is more variety in the VoIP segment, VoIP offerings tend to better fit consumers' tastes. In our example, the welfare-maximizing allocation can be shown to be $\lambda = 0.675$.

5 Conclusion

In this paper, we 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 looked at two different settings. In the first setting, which can be seen as a benchmark case, we assumed that the size of the customer segment interested in VoIP was exogenously given (hence consumer migration between the segments was not possible). In this simple

[27] For instance, a recent OECD report (OECD, 2006, p. 28) contains a statement that can be interpreted as such.

[28] Welfare in a model with full participation only depends on price differences and not on price levels.

model with inelastic demand an increase of the PSTN terminating access price increases the incumbent's profits, but as it does not affect the entrant's profits, market entry is independent of access regulation.

In the second setting, we endogenized consumers' choices for PSTN versus VoIP services. We used a set-up with the interpretation of fulfilled expectations about retail prices in the VoIP segment (this interpretation was not necessary, though). For instance, before consumers learn the prices of VoIP services, they already have certain beliefs about expected prices, which help them to figure out whether to go migrate to VoIP. Accordingly, consumers are already aware of the existence of a new technology, and make their migration decision before prices are actively searched. Another interpretation is that the decision to migrate to a new technology requires some commitment, as the effort to do so is sunk before the process of actively searching prices starts. Focusing on fulfilled-beliefs equilibria allowed us to keep the analysis tractable, while at the same time incorporating consumers' migration decisions in a realistic way.

Below we shortly discuss our main results and make some comments on the application of CPP versus RPP. 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 if the consumers' technology adoption decision is endogenous. 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 more 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. In addition, 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 even more.

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.

RPP versus CPP: Our analysis has been carried out under the "calling party pays" (CPP) principle. If, however, the "receiving party pays" (RPP) principle is applied, then the user of the PSTN network has to pay for terminating access of the calls that he receives. This implies that the perceived cost of the VoIP operator no longer contains any payment for terminating access. In that case, if the PSTN operator charges a higher price to his PSTN customers for receiving calls, he makes PSTN telephony less attractive and will therefore reduce his PSTN customer base. Thus the comparative static results with respect to market share are reversed. Furthermore, under fulfilled expectations the price level of the VoIP segment is independent of the relative success of VoIP.

This suggests that with the appearance of VoIP the rationale for applying the case for applying RPP is strengthened. More generally, with the coexistence of different technologies, technology-specific costs have to be attributed to users, ignoring the issue of markups. Under RPP, costs of PSTN telephony are attributed to PSTN users whereas under CPP, they are partly borne by VoIP users. However, to the extent that some of the costs arise due to social obligations, in particular, universal service obligations, the application of RPP may put an excessive burden on PSTN users. This burden may become unbearable if the PSTN segment shrinks drastically in size.

Our modelling strategy has been to isolate the cost effects of access price regulation abstracting from two important aspects. First, integration in our model with a given PSTN price is neutral to competition. Thus cannibalization is not an issue. This result is due to the particular timing, because an integrated firm with a regulated PSTN price cannot commit to a high VoIP price (which would avoid cannibalization). However, 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. Also note that 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.

Second, 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.

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