Access Regulation and the Adoption of a New Technology: The Case of VoIP[1]

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Abstract

The introduction of packet-switched telephony in the form of VoIP and VoB (voice over broadband) raises concerns about current regulatory practice in Europe. 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 VoB. In particular, we show that with endogenous consumer choice between PSTN and VoB telephony, higher prices for terminating access to the PSTN network make VoB less likely to succeed and lead to lower profits of operators that offer exclusively VoB telephony.

JEL-Classification: L96, L51, L13

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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), allowing entrants without their own local networks to offer voice-over-broadband (VoB) telephony. It 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 VoB 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 VoB services to another segment, while the entrant only offers VoB 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 VoB 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 VoB 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 VoB telephony, and an entrant without ties to the past. In addition, we explicitly focus on the effects of regulation on the market. In practice, national regulatory authorities (NRAs) are struggling with the question of whether they should restrict the incumbent's activities with regard to VoB, or refrain from intervening so that the market will determine how this new technology develops. Regulation may be necessary in order to prevent anticompetitive behavior, but on the other hand, intervening may easily distort innovation and its adoption process in the

[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 different setting. In particular, here we focus on terminating access whereas in De Bijl and Peitz (forthcoming) as well as De Bijl and Peitz (2006) we focus on unbundling.

market.

In this paper, we mainly focus on regulation of terminating access (in a companion paper, we consider LLU regulation in a similar situation of competition). We will also discuss the effects that the retail price in the market for PSTN telephony may have on market outcomes in the VoB segment. Accordingly, we will not so much be considering regulation of the VoB 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 the fact that an incumbent may be have a dominant position in the wholesale market for terminating access at the PSTN network. Within the European regulatory framework for communications markets, such considerations—which may be legitimate by themselves—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 such as VoB. Our aim is to articulate some of the most salient side effects of 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 VoB 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. [PRESENT AND DISCUSS SOME RESULTS HERE]

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), De Bijl and Peitz (2002), Armstrong (2002) and Vogelsang (2003). Our paper departs from that literature by analyzing an environment in which VoB networks do not charge for call termination. As we will argue, we consider this situation the natural starting point of the analysis because of the underlying principles of packet-switched networks.

Note that although technically speaking, we look at a two-way access problem, but actually, as long as VoB operators do not charge for access, our set-up boils down to a one-way access problem. Hence 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 in order to obtain efficiency of production, the access price should be set equal to marginal cost of access plus the incumbent's opportunity cost of providing access (the latter term is equal to the incumbent's lost profits due to entry). If incumbent and entrant offer perfect substitutes this rule reduces to the margin rule according to which the incumbent's lost profit equals its lost retail revenues (see Armstrong, 2002). Accordingly, if the vertically integrated incumbent is less efficient than a downstream entrant, it can increase its profits by granting access to this entrant. In this simplified world, there is no need to regulate the incumbent's access price: foreclose is unprofitable if an entrant is more efficient. 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, i.e. second-best welfare maximizing allocation through a global price cap. As becomes apparent, imperfect competition complicates the appropriate use of global price cap because supply-side and demand-side effect 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 bottleneck owner and non-integrated competitor, the regulator may want to subsidize the competitor at the margin to increase competitive pressure (see 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 (see Armstrong and Vickers, 1998, and Lewis and Sappington, 1999, see also 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 below the socially optimal level. Note that such a bias becomes less pronounced the more competitive the 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' paper can be seen as complementary to our paper.

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 VoB 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 VoB 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, our paper also contributes to the literature on multi-product firms in a multi-dimensional product space. This literature has been reviewed in Manez and Waterson (2001).[2] In this paper we provide a tractable model of multi-product competition which allows for endogenous formation of market segments and can be solved analytically. Our framework may prove 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 VoB. In section 3, we explore a model in which the group of consumers purchasing VoB services is exogenously given. Section 4 analyzes the case in which migration from PSTN to VoB services is endogenously determined. Section 5 concludes the paper.

2 Terminating access and VoB 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. For an overview of the development of LLU throughout Europe and the European regulatory framework, see De Bijl and Peitz (2005). In this paper, we abstract from LLU regulation in order to focus on regulation of terminating access (see our companion paper

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

for an analysis of regulation of LLU lease prices).

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. Examples of such applications are VoIP and VoB.

The number and variety of IP-based telephony service propositions are large and increasing. In order to clarify the focus of our paper, it is useful to recapitulate the main types of IP-based telephony that are currently being used:

1. *IP-based transport in traditional networks:* At the level of long-distance backbones, PSTN operators have been supplementing and replacing traditional circuit-switched technology with IP-based technology.

2. *IP-based offerings (VoB) from traditional operators:* PSTN operators may upgrade their local connections (consisting of traditional copper wires) to high-capacity digital subscriber lines (DSL), enabling broadband Internet access.[3] Such connections may also be used to offer VoB telephony. Operators may offer Internet access and VoB services as a bundle.

3. *IP-based offerings (VoB) 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 VoB telephony. Again, these offerings may be sold as a bundle.

4. *IP-based offerings (VoB) from entrants without local networks:* 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 VoB services to end-users.

5. *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.

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

6. *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.

7. *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.

No single type of VoIP has yet emerged as a leading type, and 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.[4]

In this paper, we restrict our focus to competition between an incumbent offering IP-based services (type 2 or 5) and an entrant with or without a local network (type 3 or 4). Note that if the incumbent is of type 5 (next generation network), we assume in our analysis that it is upgrading its network from a PSTN to an all-IP network, so that during this transition, it offers both PSTN and IP-based telephony. In case of a LLU-based entrant (type 4), we assume away problems associated with the setting of the wholesale lease price of local loops.[5] 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 Wholesale access to the local loop

The models analyzed in our paper focus, among other cases, on situations in which entrants do not have their own local access networks. An important way of getting access to end-users in such cases is through local-loop unbundling (LLU). This is typically defined as the process of disconnecting an incumbent's local connections from the rest of its network, and connecting it to another operator's network, enabling the latter operator to use the incumbent's local

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

[5] See our companion paper De Bijl and Peitz (2006).

loop to reach end-users and offer them services. The underlying idea is to enable entrants without local networks to compete in the retail market by leasing the incumbent's unbundled local loops.

The wholesale price of leasing unbundled lines from an incumbent with significant market power is typically regulated in the member states of the EU. The underlying idea is that incumbents cannot be trusted to set lease prices at levels that will generate effective competition—in the absence of network rollout—in the retail market.

The definition of LLU above is not very precise, and to some extent, besides the point. In practice, one can distinguish different degrees of disconnecting the incumbent, and based on these degrees, different types of unbundling. Basically, there are two types of LLU that give entrants access to DSL connections:

1. *Full unbundling:* an entrant gets access to the complete frequency range (narrowband and broadband) of the incumbent's copper wires, from the incumbent's main distribution frame (MDF) in a local switch to the customer's premises, enabling the entrant to provide voice and/or data services to end-users. The incumbent can no longer offer services over unbundled lines.

2. *Linesharing:* an entrant gets access to the broadband frequency range of the incumbent's copper wires, from the incumbent's "Main Distribution Frame" (MDF) in a local switch to the customer's premises, enabling the entrant to provide data services (including VoB) to end-users. The incumbent can continue to offer voice telephony over the narrowband frequency range of an unbundled line.[6]

In both cases of LLU, the entrant installs a "DSL Access Multiplexor" (DSLAM) in the incumbent's local switch, which is a piece of equipment connecting the entrant's long-distance backbone to the incumbent's MDF. The process of an entrant installing this equipment in an incumbent's local switch is known as "co-location". In the case of linesharing, an entrant also

[6] The possibility of the incumbent to do so may depend on country-specific regulatory characteristics. In the Netherlands, for instance, the regulated lease price for full unbundling is substantially substailly higher than the lease price for linesharing, based on a difference in fixed costs that are supposed to be covered. If a customer of the entrant that uses linesharing terminates his or her subscription to the incumbent, then the wholesale agreement between the entrant and the incumbent is automatically changed from linesharing to full unbundling. The rationale is that when the incumbent loses the revenues from the subscription, its fixed costs are no longer covered under line-sharing. The lease price in the case of full unbundling is sufficient for cost recovery.

installs a “splitter” in the local switch, which allows for sharing of unbundled lines according to a certain division of the frequency spectrum.

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 VoB service. Hence our analysis captures “naked” DSL (also known as “standalone” DSL), a service proposition based on linesharing 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.

Besides LLU, our model also sheds lights on entry by operators without local networks who use “wholesale broadband access” over copper wires, also know as “bitstream access”. With this type of wholesale access, entrants also connect to the incumbent’s network, but typically at a higher level in the hierarchy of the network. As a consequence, the number of locations where an entrant has to "plug in" is reduced substantially. Also, the entrant can make use of the incumbent’s DSLAMs, and doesn’t have to install its own ones. Therefore, the necessary investment is reduced. Bitstream access is, in practice, typically offered as a wholesale product to LLU-based entrants and ISPs, who face relatively modest infrastructure investments. In principle, however, it could be employed as an alternative to LLU in order to reach end-users.

2.3 Terminating access

Public telecoms networks, whether PSTN or IP-based, must interconnect with one another, so that the largest number of 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 VoB network to the incumbent’s PSTN network are delivered through a “gateway”, which allows for straightforward identification of

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

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 off-net 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 of incoming calls.

In the basis case of our analysis, we suppose that the incumbent charges for call termination 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.

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 (VoB). 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.

Thus we consider different technologies that can be used to provide voice services. This feature is then combined with the presence of heterogeneous consumers. 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 VoB to the new segment which is open to a new technology, while the entrant only aims at the latter segment by offering VoB. 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.

Throughout this section, we assume that consumers cannot "migrate" from one segment to the other, while the segment sizes are exogenously given. In the next section, we will assume that the relative size of the group of consumers who are willing to adopt the new technology is endogenously determined, that is, we allow for consumers to choose between PSTN and VoB-based telephony.

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 VoB network is 0,[8] and that operators do not charge for call termination to a customer subscribing to a VoB service. This is in line with the tendency of VoB 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. However, 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 customers with a traditional telephone subscription. Access price a is set by a regulator.[9] Since we do not explicitly model the regulator as a player, access price a is an exogenous parameter in our model. To keep the number of parameters small without loss of generality, for now we set all other costs equal to zero.

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.[10] 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

[8] We refer to marginal costs of call termination as traffic-dependent costs associated with call termination. These costs are substantially lower for IP than for PSTN networks, and therefore we set them at 0.

[9] 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).

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

on price). 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 VoB telephony is denoted by p_i, $i = 1, 2$. Note that implicitly we assume that all per-minute 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 (2004) 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 VoB providers.[11]

We assume that 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 are denoted by $s_i(p_1, p_2)$, $i = 1, 2$, and depend on the prices charged by both operators. It is natural to 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

[11] This assumption simplifies 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 VoB and VoIP services (and partly as an alternative, linear prices for calls that terminate on the PSTN network). Possibly because of the emergence of IP-based telephony, there seems to be a trend towards flat fees for all voice telephony services. Finally note that the present model may be seen as an approximation of a model with positive usage charges but rather inelastic demand.

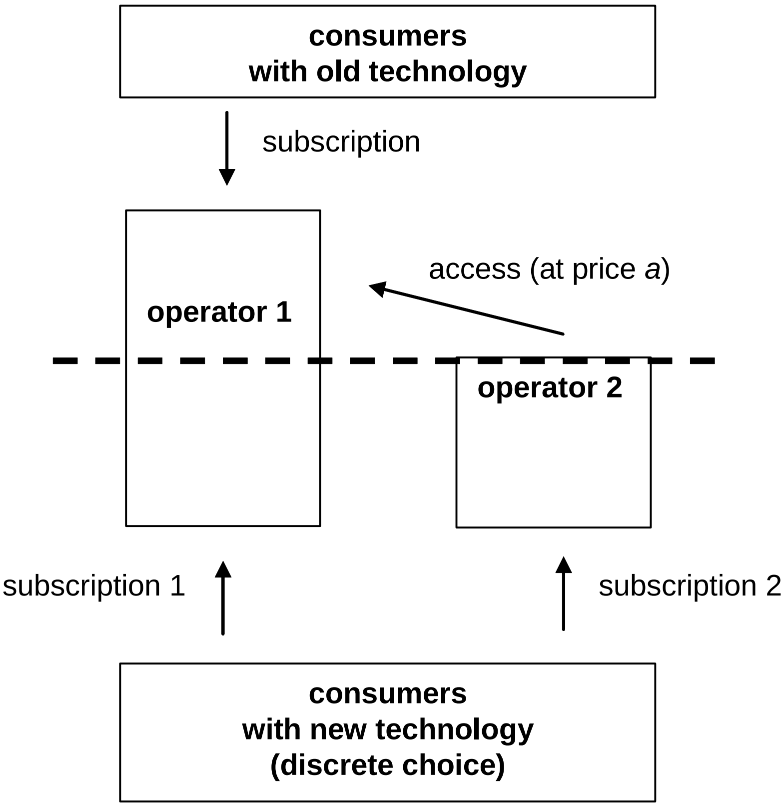

Figure 1: Illustration of the model.

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.

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

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

and firm 2's profits as

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

These profit functions reflect the volumes of on-net and off-net traffic between operator 1's PSTN network and both operators' VoB 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. the articles by 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 VoB 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

$$\max_{p_1} \pi_1(p_1, p_2^*; a, p_0), \tag{1}$$

while operator 2 maximizes

$$\max_{p_2} \pi_2(p_1^*, p_2; a, p_0). \tag{2}$$

3.2 Analysis

Recall that the two consumer groups are completely separate and their sizes are exogenously given. Consumers in the old segment always purchase PSTN telephony from the incumbent, whereas consumers in the new segment can choose between buying VoB services either from the incumbent or from the entrant.

Suppose that there exists a unique pair (p_1^*, p_2^*) which solves problems (1) and (2) 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

$$\max_{\widetilde{p}_1} \lambda_0(p_0 - \lambda_0 c) + \lambda[s_1(\widetilde{p}_1, p_2^*)(\widetilde{p}_1 - \lambda_0 c) + \lambda_0(1 - s_1(\widetilde{p}_1, p_2^*))(a - c)] + \lambda \lambda_0 \Delta a \tag{3}$$

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 (1). 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

$$\max_{\widetilde{p}_2} s_2(p_1^*, \widetilde{p}_2)(\widetilde{p}_2 - \lambda_0 a) \tag{4}$$

Clearly, p_2^* is the solution to this problem because it is equivalent to problem (2). 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 VoB telephony. Market shares remain the same.*

In other words rents are redistributed from consumers using the new technology to the bottleneck owner of the old technology. We believe 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 decisions.

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 access regulation. However, for high retail prices (which are due to a high access price), the participation or incentive constraint for some consumers becomes binding. In this case, we will not have a full pass-through of access payments to the consumers of firm 2. Rather firm 2 will have to reduce its profit margin to the effect that market entry is less likely. We will point out this effect in 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 is 1/2. This is indeed implemented by the equilibrium 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.[12]

A frequent concern of competition authorities and regulators is that a high access price can be used as an instrument by the incumbent to foreclose the market. Note that in this simple model with inelastic demand of consumers this is not the case, provided that the retail price is fully flexible. Since the access price is neutral to the entrant's profit, more generally market entry is independent of access regulation.

4 Consumers choosing between PSTN and VoB

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 VoB; 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 VoB. If they do so, they can choose between the VoB offerings of the incumbent and the entrant.

As before, the marginal cost of call termination on the PSTN network is $c > 0$, while

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

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 VoB 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 the brands that they offer), and the t dimension reflects consumers' inclinations towards VoB 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 inclined to adopt VoB, whereas a consumer with t close to 1 is rather reluctant to adopt VoB. 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. VoB-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 VoB services, but also when consumers decide whether purchase PSTN or VoB services.[13]

Consumers either subscribe to the PSTN service offered by the incumbent firm or to one of the two VoB 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 VoB-services (which may also include the firm-specific utility, see below). Parameters τ and θ measure the degree of heterogeneity among consumers. Thus a large τ corresponds to a low substitutibility between PSTN and VoB. Similarly, a large θ corresponds to a large degree of differentiation between operators.

Similarly, a consumer who purchases VoB 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 VoB 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 VoB services, they have certain beliefs about the prices that they can expect, and based on these

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

beliefs, they figure out whether to go for VoB 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 VoB services. She 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. If it turns out that VoB is too expensive compared to its benefits, she may still opt for PSTN services. Note, however, that 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 VoB, *before* VoB-prices are searched.[14]

An alternative way of understanding this specification is to argue that the decision to migrate to VoB involves a certain level of commitment, as the effort to make a first comparison between PSTN and VoB services has been sunk, 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.[15]

Consumers have identical beliefs about VoB 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 describe beliefs by $\widehat{p}_1$ and $\widehat{p}_2$.

Profit functions: Note that profit functions have the same form as specified in the previous

[14] 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. Future work may want to analyze look at such a model.

[15] An alternative specification would be to assume that consumers do have price information before making their migration decision. This would give the entrant more possibilities to penetrate the market with its VoB services and would introduce an additional strategic dimension into the problem. Namely, the incumbent could make the VoB segment on average less attractive by increasing its price.

section. By incorporating the new elements into the game, 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 structure:

$t=0$: PSTN price p_0 is exogenously given (set by the regulator), and observed by all consumers as well as operator 2.[16]

$t=1$: Each consumer learns his or her preference parameter $t\in[0,1]$, reflecting an individual's inclination towards PSTN versus VoB. All consumers form expectations about VoB prices $\widehat{p}_1$ and $\widehat{p}_2$.

$t=2$: Given their preferences and beliefs, consumers decide whether to go for PSTN or VoB. At the same time, the operators (simultaneously) set VoB 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 among buying PSTN telephony from the incumbent, VoB telephony from the incumbent, or VoB telephony from the entrant.

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 3, 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 $p_2^*=\widehat{p}_2$.

4.2 Analysis

We start by looking at consumers' choices at the last stage, $t=3$, for those consumers who have chosen to adopt VoB. There consumer who is indifferent between the two VoB 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,

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

if a fraction λ demands VoB-services, then the total demand for VoB 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 $t = 1$, 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 VoB 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 VoB services. Compared to the average price for VoB 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 $\overline{t}$ of the consumer who, given his beliefs about VoB prices, is indifferent between PSTN and VoB 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 VoB 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, 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 $t = 2$, when consumer beliefs are given, $\lambda(p_0, \widehat{p}_1, \widehat{p}_2)$ and $\lambda_0(p_0, \widehat{p}_1, \widehat{p}_2)$ are given, as in the previous section, and hence can be treated as fixed parameters. This simplifies the profit functions that were given by

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

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 VoB, the Nash equilibrium at $t = 2$ is characterized by the following prices:

$$p_1(p_0, \widetilde{p}) = \frac{3\theta + U_1}{3} + \frac{a}{2} + \frac{\widetilde{p} - p_0 + U_0}{2\tau}a, \tag{5}$$

$$p_2(p_0, \widetilde{p}) = \frac{3\theta - U_1}{3} + \frac{a}{2} + \frac{\widetilde{p} - p_0 + U_0}{2\tau}a. \tag{6}$$

Some interim observations can be made from based on (5)-(6) under the assumption that $\widetilde{p}$ is fixed. Clearly, if the VoB services are closer substitutes (θ smaller), then lower prices result. Brand loyalty or superior performance of firm 1's VoB 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 in the present specification. (This is trivially true because 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 VoB services. This is due to the cost effect that

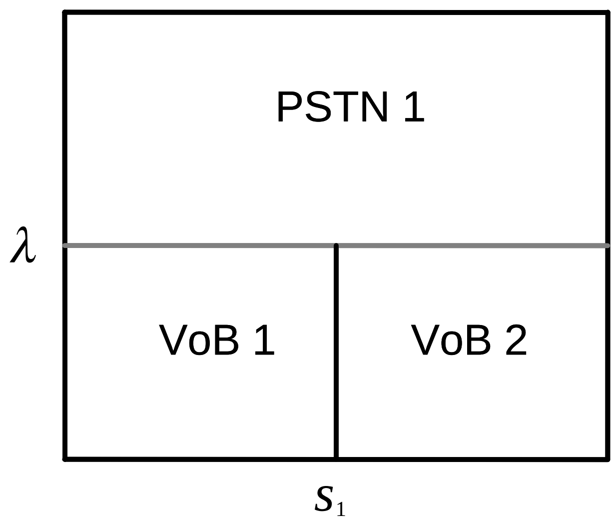

Figure 2: Division of the market.

a higher p_0 will lead to less demand for PSTN services, which reduces the likelihood that subscribers to operator 2's VoB 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 VoB price $\widetilde{p}$, and for the fixed-utility advantage of PSTN compared to VoB services, U_0.

The price function in (5)-(6) 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

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

then the equilibrium value $\widetilde{p}^*$ is defined as a fixed point of $g(\cdot)$. In our model, $g(\cdot)$ turns out to be linear in $\widetilde{p}$, so that there exists a unique fixed point $\widetilde{p}^*$. It is straightforward to calculate that

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

The quality-adjusted average price for VoB services is decreasing in the utility of firm 1's VoB 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 VoB more attractive, everything else equal, as explained above. Therefore, in an equilibrium outcome, pricing in the VoB segment becomes more competitive (and therefore, $\widetilde{p}^*$ falls).

Substituting the constant $\widetilde{p}^*$ into (5)-(6), we obtain the equilibrium size of the PSTN segment:

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

Recalling that $\lambda^* = 1 - \lambda_0^*$, we can now make the following observations:

Result 4.1. *In an equilibrium outcome,*
(i) a higher price for PSTN telephony leads to a larger customer base for VoB telephony; and
(ii) a higher access price for call termination on the PSTN network leads to a smaller customer base for VoB telephony.

Observation (i) is not surprising. If PSTN telephony becomes more expensive, more consumers will switch to VoB. Observation (ii) is less straightforward: a higher access price for PSTN telephony hinders the migration to VoB services and is therefore a hurdle in the transition process from PSTN to VoB. We will further elaborate on this below, when we discuss equilibrium prices in the VoB segment.

Next, we can write down the equilibrium prices for VoB services:

$$\begin{aligned} p_1^* &= \theta + \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 30\theta U_1 - U_1^2\} + 24\theta(3\theta + U_1)\tau}{36\theta(2\tau - a)}, \qquad (7) \\ p_2^* &= \theta - \frac{U_1}{3} + \lambda_0^* a \\ &= \frac{a\{9\theta[4(\tau - p_0 + U_0) - \theta] - 6\theta U_1 - U_1^2\} + 24\theta(3\theta - U_1)\tau}{36\theta(2\tau - a)}. \qquad (8) \end{aligned}$$

Note that if an equilibrium exists, it is unique (given by (7)-(8). 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 holds, for instance, in a symmetric setting (i.e. $U_0 = U_1 = 0$) provided that $p_0 > a$ and $\tau > 3/4\theta$. In addition, for the formula to be valid, we must have $s_i(p_1^*, p_2^*) > 0$ for $i = 1, 2$, that is, no operator corners the VoB market.[17]

The insight from the previous section with respect to prices in the VoB-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.

We can make a number of observations based on (7)-(8):

Result 4.2. *In an equilibrium outcome,*
(i) provided that the PSTN access price is positive, a higher price for PSTN telephony leads to lower prices for VoB telephony;
(ii) provided that the PSTN access price is zero (equal to cost), a higher price for PSTN telephony does not affect prices for VoB telephony;
(iii) a larger fixed utility level specific for PSTN telephony (relative to VoB telephony), leads to lower prices for VoB telephony; and
(iv) a higher access price for call termination on the PSTN network leads to higher prices for VoB telephony if and only if $9\theta[4(\tau - p_0 + U_0) + 3\theta] - 18\theta U_1 - U_1^2 > 0$.

Let us discuss these observations in some more detail:
(i)-(ii): 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 more competitive outcome of competition in the VoB segment. Thus we have here an example in which products in two segments are substitutes, firms are price setters in one segment and face a mandated price in the other segment. Nevertheless products are strategic substitutes. The reason is that for given shares λ and λ_0, the access cost effect is the driving force. Note 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.

[17] 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.

(iii): By a similar argument, a larger value for U_0 increases the customer base for PSTN services, and hence inflates the entrant's perceived marginal cost. Therefore,

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

Note that a larger U_0 corresponds to relatively less fixed utility that is specific for VoB, but operator-independent (a parameter that is not in the model). Quite naturally, this makes migrating to VoB less attractive, forcing the VoB operators to reduce their prices.

(iv): Notice that for $i = 1, 2$,

$$\begin{aligned}\frac{\partial p_i^*}{\partial a} &= \lambda_0^* + \frac{\partial \lambda_0^*}{\partial a} a \\ &= \lambda_0^* + \frac{\lambda_0^*}{2\tau - a} \\ &= \frac{\tau\{9\theta[4(\tau - p_0 + U_0) + 3\theta] - 18\theta U_1 - U_1^2\}}{18\theta(2\tau - a)^2}.\end{aligned}$$

Accordingly, $\frac{\partial p_i^*}{\partial a} > 0$ if and only if $9\theta(4(\tau - p_0 + U_0) + 3\theta) - 18\theta U_1 - U_1^2 > 0$. If the parameters satisfy the latter condition, which is for instance the case for parameter configurations such that p_0 and U_1 are sufficiently small, then the intuition is similar as above: a higher access price a softens competition in the VoB segment. More precisely, the entrant's perceived marginal cost increases, inflating its retail price p_2. This allows the incumbent to increase its VoB price p_1 as well. 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 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 is independent of a. However, firm 2's profits are not neutral to the access price. The reason is that consumers, anticipating higher VoB prices, become more reluctant to migrate to VoB.

We will now discuss how the operators' profit levels are affected by changes in the parameters. As consumers know that a higher access price makes the VoB market less competitive, operators in the VoB segment will face a smaller share of customers, and thus, one can expect that operator 2's profits are reduced. However, we will see that this depends on the parameters.

To make things more precise, note that 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

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

A couple of comparative statics properties are worthwhile mentioning.

(1) 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 VoB-segment. This in turn leads to lower perceived costs of firm 2 and thus to a more competitive outcome.

(2) 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, if

$$\frac{d\pi_2^*}{da} = -s_2^* \left[\lambda^* \lambda_0^* + \frac{\partial \lambda^*}{\partial a}(\lambda_0^* - \lambda^*)\right] < 0$$

This is equivalent

$$-\frac{(3\theta - U_1)^2[9\theta(4\tau - 4p_0 + 4U_0 + 3\theta) - 18\theta U_1 - U_1^2]}{8(2\tau - a)^2} < 0.$$

For $U_1 = 0$, the condition reduces to

$$-\frac{\theta(4\tau - 4p_0 + 4U_0 + 3\theta)}{8(2\tau - a)^2} < 0$$

As we explained before, higher perceived costs drive firm 2's profits down and the profit neutrality result breaks down. For instance, in the examples below this condition is satisfied.

The equilibrium expression for firm 1's profit is even more involved and reported in the appendix [TO BE DONE]. We illustrate some of the comparative statics properties of firm 1's profits with numerical examples.

(1) 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 VoB segment is in expectations more valuable than a consumer in the PSTN segment the shift from PSTN to VoB is actually 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 VoB. This confirms that VoB-offers by firm 2 give rise to some disciplining effect on the firm 1's PSTN offer. [A STRAIGHTFORWARD EXTENSION IS ALLOW FIRM 1 TO COMMIT TO A PRICE p_0; motivation: firm needs regulatory approval for the price]

(2) Firm 1's profit may be partly increasing and partly decreasing in the access price a. This suggests that it is not necessarily in the interest of firm 1 to lobby for a high access charge, given the retail price in the PSTN-segment p_0. In particular, if p_0 is small firm 1's profit is globally decreasing in a. The reason is the following: With a higher access price a consumers expect the VoB-segment to be less competitive. Therefore only few consumers decide to migrate to the VoB 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 holds true since it would like to convince consumers to more to the VoB segment.

For a larger p_0 firm 1's profit are initially increasing in a. For small a a consumers in the PSTN segment is then in expectations more valuable for firm 1 than a consumers in the VoB segment. Thus, an increase in a which shifts consumers from the VoB to the PSTN segment is profit increasing. This no longer holds for larger a. The reason is that for larger a, competition in the VoB segment is more relaxed so that, for retail prices in the VoB segment are above a certain level, a consumer in the VoB segment is in expectations more valuable than a consumer in the PSTN segment. This is illustrated in figure 3. In this numerical example, firm 1's profit reach a maximum at approximately $a = 0.286$ holding all other parameters (and regulatory variables) fixed.

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

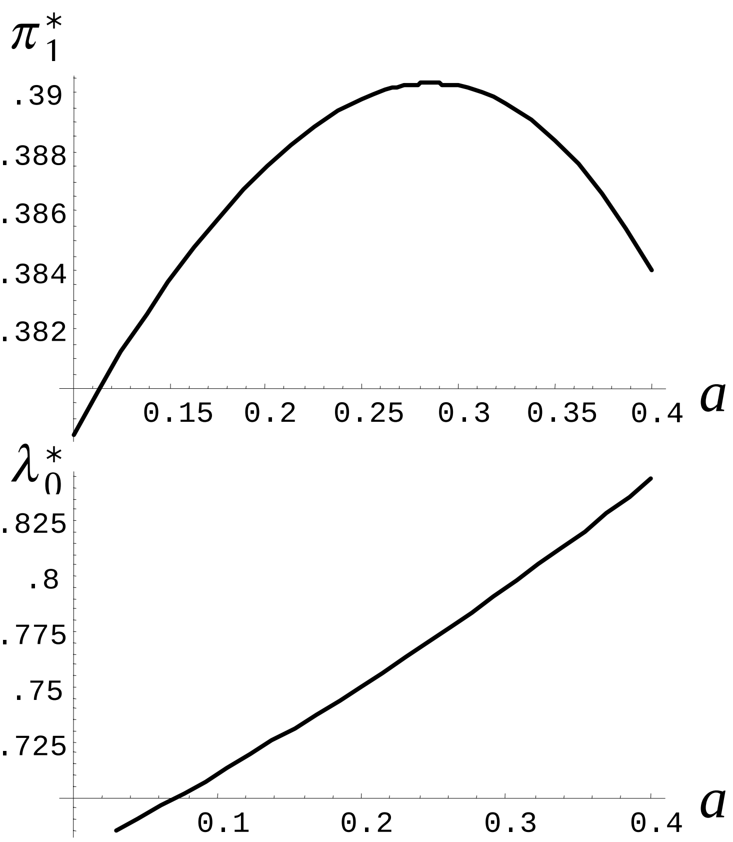

Figure 3: Firm 1's profit and size of the PSTN segment depending on a (for $p_0 = 0.4$, $\theta = \tau = 1$, $U_0 = U_1 = 0$)

5 Discussion

5.1 Regulation of retail prices

An important result of the analysis was that, as long as the PSTN access price is positive (or more generally, above the marginal cost of call termination), a higher price for PSTN telephony leads to lower prices for VoB telephony. For an access price equal to zero (or to marginal cost), the retail price level of PSTN telephony does not affect retail prices for VoB telephony. These results illustrate the links between different telephony networks—links that should not be ignored.

A straightforward interpretation of these results is that cheaper PSTN telephony leads to a smaller customer base for VoB telephony. However, the underlying mechanism depends on the fact that an entrant in the VoB market faces an inflated marginal cost if the incumbent's PSTN access price is higher. This softens price competition among VoB operators.

More particularly, 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. Consequently, if a universal service obligation forces the incumbent to price PSTN telephony at a low level, VoB retail prices become inflated and the emergence of the VoB market will be slowed down.

5.2 Regulation of terminating access prices

[TO BE DONE]

5.3 RPP versus CPP

Our analysis has been carried out under the calling party pays principle. If, however, the receiving party pays principle is applied 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 VoB operator does not contain any payment for terminating access. In this 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 expectation the price level of the VoB segment is independent of the relative success of VoB.

This suggests that with the appearance of VoB the rationale for applying the receiving-party-pays principle is strengthened. More generally, with the coexistence of different technologies technology-specific costs have to be attributed to users, ignoring the issue of markups. With the receiving party pays principles costs of PSTN telephony are attributed to PSTN users whereas under the receiving party pays principle they are partly borne by VoB users.

However, to the extent that some of the costs arise due to social obligations, in particular, universal service obligations the application of the receiving party pays principle may put an excessive burden on PSTN users. This burden may become unbearable if the PSTN segment shrinks drastically in size.

6 Conclusion

In this paper, we explored competition between an incumbent offering both PSTN and VoB telephony, and entrant active only in the VoB segment. To be able to analyze competition between operators offering PSTN and VoB services, we had to make a couple of simplifying assumptions. To do so, we looked at two different settings.

In the first setting, we assumed that the size of the customer segment interested in VoB was exogenously given. This set-up generated some interesting results, but did not allow us to incorporate consumer migration from PSTN to VoB telephony. The main result was that an increase of the PSTN terminating access price increases the incumbent's profits, while leaving the entrant's profits unaffected. This can be explained by the fact that both operators pass on the access price increase to consumers in the VoB market segment.

In the second setting, we endogenized consumers preferences for PSTN versus VoB services in a set-up of fulfilled beliefs about retail prices in the VoB segment. One interpretation is that before consumers learn the prices of VoB services, they already have certain beliefs about expected prices, which help them to figure out whether to go migrate to VoB. 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.

[SUMMARY OF MAIN RESULTS]

[SHORT DISCUSSION OF POSSIBLE EXTENSIONS]

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