Network Competition with Consumer Switching Costs: A Model for the Telecommunications Sector

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Abstract

This paper gives a model for price competition under consumer switching costs in a network setting with interconnection charges. This simultaneous analysis is conducted in a discrete choice model with a multinomial logit differentiation for the customers and not in a traditional Hotelling framework. Analytical equilibrium results are derived for duopoly competition between identical firms with both homogeneous and heterogeneous customers. A numerical method was used to study the effects of having different installed bases and to allow for the introduction of market growth.

Key words : switching costs, entry, mobile telecommunications, market growth.

JEL Classification: L11, L13, D43

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1 Introduction

During recent years the telecommunications sector went through a number of tremendous changes. The sector has been liberalized and has changed from a market with regulated monopolies in many countries to a competitive market structure. The changes had an in‡uence on the price levels, on the number of services o¤ered and on the adaptation rates of new technologies (see e.g. Gruber and Verboven, 1999). The growth rates of the sector are very high (see e.g. Raadgevend Comité voor de Telecommunicatie, 2000, Table 4.1, p. 106).

Introducing competition in a previously monopolized market implies entry of new …rms. An entrant is faced with some speci…c problems once he enters the market. The …rst problem an entrant faces is acquiring market share when some of the customers are locked in. Gaining market share means persuading customers to buy from him instead of from the incumbent. Customers can be one of two types: customers new in the market or customers who already bought from the incumbent. In most cases, it will be harder to persuade a customer to buy from the entrant if he already bought from the incumbent in the previous period then if he is new in the market. The reason are switching costs faced by a customer when he changes from supplier. On the other hand it is often possible to …nd a small fraction of customers that does not whishes to stay with the incumbent regardless of the switching cost they face. The second problem encountered by an entrant is typical for the telecommunications sector: interconnection between networks. An entrant must interconnect with the existing …rms to be able to deliver a complete service to his customers. Without interconnection an entrants …rst customer would not be able to call anyone.

In what follows I will try to build a model that makes it possible to study the two problems faced by an entrant at simultaneous: interconnection and gaining market share under switching costs. This simultaneous study of both problems is an addition to the existing literature (see section 2). A further di¤erence between most of the literature and this paper is the model used: a discrete choice model with a multinomial logit di¤erentiation for the customers whereas other papers often use a traditional Hotelling. I can show that using this type of model in combination with switching costs allows to …nd equilibrium prices for both heterogeneous and homogeneous customers in a duopoly model with identical …rms which is an extension of the existing literature. The theoretical symmetric model is further extended to allow for numerical analysis of two market asymmetries: di¤erent market growth rates and di¤erent initial market shares of the …rms. One of the surprising results that come out of this numerical analysis is that under certain parameter choices the entrant is better of by charging a higher price than the incumbent. A possible explanation lies in the interplay between switching costs and interconnection charges. Further research might be require.

The remainder of the paper is as follows. Section 2 gives a brief overview of the existing literature both on network interconnection and on switching costs. Section 3 takes a closer look at some speci…c aspects of the telecommunications sector. In section 4 the discrete choice model is build. Section 5 looks at price competition with identical …rms while section 6 studies price competition under market asymmetries. Section 7 …nishes with some concluding remarks.

2 Literature

The relevant literature for this paper is subdivided in two main topics: network competition and switching costs.

Concerning network competition two of the most in‡uencial papers are Laffont et al. (1998a) and La¤ont et al. (1998b). In the …rst of these two papers the authors look at unregulated competition between interconnected networks. The …rms, di¤erentiated in a Hotelling way, engage in price competition for customers who make a discrete choice. There main results are that even in a mature market a competitive equilibrium may fail to exist if the interconnection charges and/or the network substitution e¤ects between …rms are large. If an equilibrium exists there is a positive relation between the level of interconnection charges and the …nal prices and pro…ts. In a market with entry, conditions are identi…ed for which an entrant will over- or underinvest in coverage. Introducing two part tari¤s allows the …rms to gain market share without incurring an access de…cit. The second paper (La¤ont et al., 1998b) introduces price discrimination depending on the destination of a phone call. The authors show each of the networks gains from using price discrimination. Surprisingly, consumer welfare may still be increased when both operators are equal and faces a higher level of competition because the interconnection charges raises their costs. The authors also show that entry will be di¢cult due to network e¤ects unless the entrant has a full coverage. Both papers are heavily based on previous work of the authors (La¤ont et al., 1997) in which a …rst indication of most results can be found.

A similar type of model is used in Carter and Wright (1996) and in Armstrong (1998). Armstrong (1998) looks at a situation in which networks must interconnect to deliver a full service to their customers. The author looks at two case, an unregulated market that is symmetric for both …rms and a market with a dominant regulated …rm. It is shown that under symmetry and in the presence of enough product di¤erentiation the two operators will agree on a reciprocal access charge that is higher than the actual cost of access although it would be welfare maximizing to put a price below the actual cost. The author points out that the regulator might play a role there. If one of the …rms has an incumbency advantage, no agreement on a reciprocal access charge will be reached. Carter and Wright (1996) look at deregulated network interconnection with the …rms that compete in the …nal retail market. Both a mature industy and entry situations are looked at. In their model, an incumbent will use interconnection issues to maintain his dominance when faced with an entrant. The authors even identify a risk of collusion over the access charges in the retail market. They suggest that the government should regulate access charges, taking into consideration the cost of regulation.

The results of Carter and Wright (1996) concerning collusion are not con…rmed by Dessein (1998a, 1998b). In his …rst paper (Dessein, 1998a) the author ask if e¤ective competition is possible in a deregulated network. The author shows there is no scope for collusion due to access charges as long as optimal non-linear tari¤s are used. The author gives two warnings concerning the access charges. First, access charges can give one of the competitors a higher pro…t which will in‡uence the bargaining position of the …rms. Second, operators may agree to use a higher than necessary access charge for two-way access to cover up their true costs of connection. This second warning is especially important when a regulator uses information on a negotiated two-way access charges to determine a regulated one-way access charge. The analysis is repeated for unbalanced calling patterns (Dessein, 1998b). When customers have unbalanced calling patterns the pricing decisions of the …rms are changed because the di¤erent types of customers will have a di¤erent value for the …rms depending on the level of access charges. For instance when the paid access charges are low, it is pro…table to have customers that generated outgoing calls. The author also shows that preventing entry by use of an access charge will only work when pro…ts are low but under those circumstances it is often bene…cial for the monopolist to allow the entry.

An interesting paper on a networks is written by Crémer et al. (1999). The authors of this paper look at the backbone market of the internet. They look at the strategies of a dominant …rm in that market and the strategic variable under consideration is the quality of the interconnection.

The papers of Armstrong (1997) and Valletti and Cave (1998) look at network competition not only from a theoretical point of view but also from a regulating one. Valletti and Cave (1998) speci…cally look at the UK-market which was one of the …rst to liberalize in Europe (Hulsink, 1999).

The paper by Aoki and Small (1999) forms a good link between both parts of this literature overview. In this paper both the interconnection issues and switching costs are combined to look at the e¤ects of a sudden drop in switching costs. The direct cause of this paper was the introduction of number portability in some countries. Number portability reduces the switching costs but the authors show that it is not always bene…cial for the customers to have it introduced. My paper will distinguish from their's in that I use the combination switching costs and access fees to look at problems of entry, while Aoki and Small had the number portability topic in mind. A second di¤erence will be the di¤erentiation process, Aoki and Small use a Hotelling type of di¤erentiation while I will use a multinomial logit model (see section 4).

The literature on consumer switching costs has mainly started with the series of articles by Klemperer[1]. In Klemperer (1987c) the author shows that a non-cooperative equilibrium in an oligopoly with switching costs may be the same as the collusive outcome in an otherwise identical market without switching costs. In the periods with consumers switching costs the competition is less hard but there is vigorous competition for market share in the preceding periods.

[1] A good overview of the literature can be found in Klemperer (1995).

Klemperer (1987a) looks at the competitiveness of markets with switching costs in a two period di¤erentiated products duopoly. The second period prices are higher then the …rst period prices. The author shows that the demand in both periods is less elastic then without switching costs. The second period is less elastic because consumers are locked in, the …rst period because rational consumers expect to be locked in in the second period. Overall, prices will be higher with switching costs then without. The presence of consumer switching costs also allows to deter entry. Depending on the exact market situation limit-over pricing or limit-under pricing can occur (Klemperer, 1987b). Limit-under pricing means that a …rm will charge a lower price now to gain a greater market share. Limit-over pricing is charging a price that is too high so that one gains little market share. This has a signalling function to a possible entrant: "watch out, I don't have a big market share so I won't have anything to loose if you enter and I will …ght hard." Klemperer (1989) also looked at price wars in a four period model with entry. The entrant will charge the lowest price during the entry period and a higher price afterwards. The incumbent will charge a low price during the entry period or in the preceding period (which is limit-under pricing) and charge a higher price in later periods. Another paper about price wars triggered by entry is Elzinga and Mills (1999). This paper has as special feature the use of heterogeneous switching costs which imply that customers actually switch in equilibrium.

Farrell and Shapiro (1988) used an overlapping-generations duopoly model with an in…nite number of periods. This basically means they allow for a fraction of new customers each period. They …nd that the incumbent will concentrate on the old customers and that in each period the new customers are left for an entrant. This process makes entry an attractive option and will lead to excessive entry. The incumbent will only deter entry if there are scale economies. Beggs and Klemperer (1992) also …nd that switching costs can make a market more attractive to an entrant even if part of the market is already committed. To (1996) uses a slightly di¤erent approach. The author works with an overlapping-generation model for an in…nite number of periods but customers are only allowed to be in the systems for two periods: they have a …nite horizon. In the speci…cation of To, the incumbent does sell to both new and old customers which is more realistic then the result from Farrell and Shapiro (1988).

Caminal and Matutes (1990) endogenized the switching costs. They get endogeneous switching costs by letting a …rm precommit to charging a certain price in the next period or to giving a certain discount. The equilibrium pro…ts from committing to a certain price are lower then the pro…ts of not committing at all. On the other hand, the equilibrium pro…ts of committing to a discount are higher then without commitment. The authors also …nd that when the …rms have the option to choose their type of commitment, only the price equilibrium survives.

My paper tries to combine the two strands of literature given above in a way that corresponds more or less to the problems faced by an entrant. I will use a discrete choice model like La¤ont et al. (1998a) but with a multinomial logit di¤erentiation (see section 4) instead of an Hotelling di¤erentiation. The logit speci…cation makes an easy introduction of consumer switching costs possible and allows to have actual switching of customers in equilibrium like in Elzinga and Mills (1999).

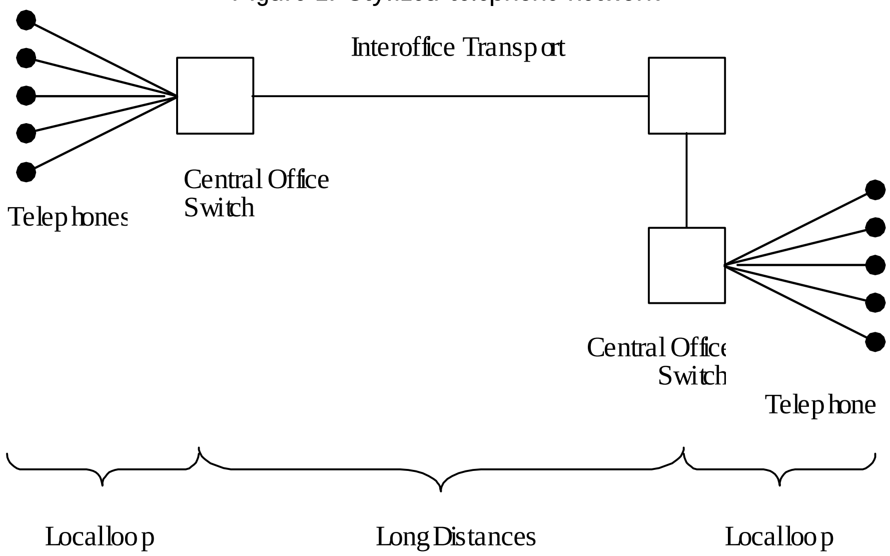
3 Telecommunication Sector

The telecommunication sector has gone through some dramatic changes during the last decades. The industry changed from local (and often state-owned) monopolies to an oligopolistic industry in many countries. To give a better picture of what happens in the telecommunications one …rst needs to know what a telecommunications network consists of. That will be the topic of the …rst subsection. In the second subsections I will brie‡y look at the evolution in the telecommunication sector.

3.1 A simple telecommunication network

A telecommunication network can be represented in a stylized way as given in …gure 1.

Figure 1: Stylized telephone network



Source: Figure based on Mitchell and Vogelsang (1991, p. 9)

In figure 1 we can recognize the following facilities of which a telecommunication network basically consists[2]:

- **Local Loop**: the final connection between the customer and a central office switch or local exchange.
- **Central Switch/Local Exchange**: facility to redirect calls either to an other local loop for local calls or to a long distance network.
- **Long Distance Network/Backbone System**: facility to handle the traffic between different local exchanges.

The technology used for the local loop was traditionally a single wire connecting a fixed telephone. New technologies to provide the local loop are now available, e.g. wireless communication, cable, satellite. The backbone system used for long distance communication often uses glass fibre, micro-wave or satellite communication. For an overview of new technologies used in the telecommunication sector I refer to the book by Mirabito (1997)

Note that the different parts of the network can be owned by different operators and that several networks can coexist in one market. If two or more networks are operating it is possible to distinguish between **on-net calls** (both the caller and person being called belong to the same network) and **off-net calls** (caller and person being called belong to competing networks). In the case of an off-net call both networks need to interconnect to let that call take place. Network interconnection implies that networks have access to each other customers. When a network needs access to a rival network to pick up a call at its originating end one speaks of **originating access**. **Terminating access** takes place at the receiving end of a call. A network needs access to a rival's customer to deliver a call from one of its own customers. Depending on whether both operators need access to each others network or only one of them needs access to the network of the rival one speaks of **two-way access** or **one-way access** respectively. One-way access happens for instance when an operator only owns a backbone and competes with an operator who has installed a complete network.

To gain access to another network an **access or interconnection charge** has to be paid. An access charge is **reciprocal** when both neworks pay each other the same access charge. Charging a reciprocal access charge is not identical as using a **bill and keep** system under which the networks do not charge each other interconnection charges. Both systems are only identical if the assumption of **balanced calling patterns** is made. Under balanced calling patterns the fraction of on-net calls a customer makes is equal to the fraction of customers that belong to this same network.

To enhance the understanding of the remaining parts of this paper the following distinction is needed : **coverage** is the fraction of potential customers that a network can physically serve, where **installed base** refers to the fraction of customers that were served by the operator at the beginning of a period.

[2] For definitions see e.g. Belgacom (2000, p. 6-14).

Building an telecommunication network requires huge investments, see for instance table 2 from Gruber (1998, p. 16) for annual investment in telecommunications in the E.U. (figures up to 1996). The different parts of the network have their own marginal costs of operation as does the network as a whole. An extra sunk cost for the operators are the licences fees to get permission to operate a mobile network. The licence fees for GSM 900 MHz spectrum in the E.U. (1992-1995) are given in Gruber and Hoenicke (1998).

3.2 Telecommunications: a sector in evolution

In the past the telecommunication firms were almost in every country state-owned or regulated private monopolies[3]. Often cited reasons for having these monopolies were (e.g. Gruber, 1998, p. 8):

- Enormous sunk costs : installing a wire network demanded an enormous long-term investment.
- Economies of scale concerning the infrastructure.
- Ensuring universal services. Having a state-owned or a regulated monopoly made it possible to require the deliverance of telecommunication services even in regions where it would be economically none-profitable (Herbert and Castello, 1988, p. 30-33).

The enormous sunk costs whose duplication was not profitable nor desirable (Laffont and Tirole, 1999, p. 3) and the presence of economies of scale made the monopolies so called "natural monopolies"[4].

During the last decades the above mentioned situation has changed significantly. A liberalization process has taken place and the sector has become very competitive. Especially the mobile sector in the European Union has known enormous growth rates. This growth has been mainly driven by technological changes and new regulations of which liberalization and technical standardization formed the cornerstones (Gruber, 1999, p. 522).

The technological innovation has a number of consequences (e.g. Gruber, 1998, p. 6). It allows for lower costs of entry into the industry and lower costs to operate a network. New technologies make it possible to get local access to the customers via other ways then a single wire. The "natural monopoly" characteristics of the local loop have thus been broken.

The liberalization of the sector has come around for a number of reasons. Herbert and Castello (1988) already point at the growing belief that Europe was lagging behind in information and communication technology compared with the US and Japan. The authors also point out that the European market was very fragmented which prevented the development of Europe-wide services (Herbert

[3] For a history of the Belgian telecommunication sector I refer the interested reader to the book of Verhoest et al. (1991).

[4] For a link between economies of scale and natural monopolies see Tirole (1989, p. 15-21) or Greene (2000, p. 70).

and Castello, 1988, Box 20). To get an overview of the analogue standards in use in Europe see for instance table 1 from Gruber and Verboven (1999). The growing awareness of the ine¢ciency of the incumbent monopolists was another reason for the liberalization (La¤ont and Tirole, 1999, p. 3). A monopolist had poor incentives to reduces costs or to innovate and under a monopoly the price structure was severely distorted.

The European Commission played a leading role in the liberalization process. Key points of this process were enforced by European law. See table 3 in appendix A for a list of those key points. The European law formed a framework in which the di¤erent countries pursued a liberalized market. The book by Hulsink (1999) gives a good overview of the privatization and liberalization in three European countries: Britain, the Netherlands and France[5]. These countries each applied the European law in there own way.

An important decision on the European level was the introduction of an E.U.-wide technical standard for mobile telephony. Table 1.2 from Mouly and Pautet (1992, p. 29) gives an overview of the di¤erent milestones in the establishment of the GSM standard. Bene…ts from the standardization are European-wide roaming, removal of obstacles for competition between equipment suppliers, cheaper development and production at lower unit costs of equipment (Gruber, 1999, p. 523).

As the sector of telecommunications is in constant evolution there are some issues that receive a great deal of attention in present discussions. The following four topics form a non-exhaustive list. A …rst and already mentioned topic is access pricing. The setting of this access price is very important because it can be used as an strategic variable (European Commission, 1995). A second topic of concern are the licences for a new mobile standard. In many countries these licences are being auctioned o¤ by the government. These auctions are heavily discussed (see e.g. Bouckaert, 2000; O¤erman and Potters, 2000). Third is the discussion about universal service which is the provision on demand of "basic" telephony services to any customer who requires it. Under a monopoly situation the universal service was guaranteed by the monopolist. The costs of providing the service were covered by cross-subsidization (European Commission, 1994, p. 1-4). Under the present oligopolistic market new approaches to universal service had to be found (Mitchell and Vogelsang, 1991, chapter 11) or (European Commission, 1994, chapters 2-4). A last hot topic are multimedia applications. The sector of telecommunications becomes more and more a sector of multimedia applications. A simple and well known example is the internet.

[5] For survey about the Belgian telecommunication sector I advise you to look at recent work of Bouckaert (2000).

4 Model

4.1 Without reciprocal access charges

4.1.1 Cost structure

If the firms in the industry both have a full coverage I can assume that both have the same cost structure. The marginal cost of a phone call for the operator can be divided into three parts : the marginal cost c_0 at the originating local loop, the same cost c_0 at the terminating local loop and the marginal cost c_1 in between. A firm faces the following total marginal cost per call

$$c \equiv 2c_0 + c_1. \tag{1}$$

A firm must also pay a fixed cost $f \geq 0$ to connect a customer to its network and a fixed cost $F \geq 0$ to maintain the network. In what follows I assume, unless stated otherwise, that $F = 0$.

4.1.2 Demand structure: a discrete choice model

A customer faces two decisions problems on the demand side: which firm will he buy from and how much will he buy given the price of that firm. As the two decision problems are interconnected, I will work with a discrete choice model in which a customer buys from the firm that gives the highest utility and the utility is a function of both the price payed and the quantity consumed

Assume we have a duopoly and name the firms, for convenience, firm 1 and firm 2. Customers make a discrete choice between the firms based on the utility they will receive[6]. In every period the customer must make this choice and as a consequence there are two types of customers : customers who bought from firm 1 (type 1) and customers who bought from firm 2 (type 2). Each firm has an installed base of customers who bought from it in the previous period[7].

Let the gross surplus a customer gets from consuming the amount q be given by $sur(q)$ which is defined as

$$sur(q) = \frac{q^{1-(1/\eta)}}{1-\frac{1}{\eta}}, \tag{2}$$

with η the elasticity of demand. In a similar way it is possible to define the net surplus a customer gets from consuming the amount q at a price p as

$$\widetilde{sur}(q;p) = \frac{q^{1-(1/\eta)}}{1-\frac{1}{\eta}} - pq. \tag{3}$$

If a customer chooses an optimal amount q^* at the price p, we find the following amount

$$q^* = p^{-\eta}, \tag{4}$$

[6] An extension of this model where the customers have the option not to buy can be found in Van De Wielle and Verboven (2000).

[7] In the case of entry this installed base is zero.

which implies a constant elasticity demand unction

$$q(p) = p^{-\eta}. \tag{5}$$

Using the optimal amount (4) in (3) we find the net indirect surplus $v(p)$ defined as

$$v(p) = \eta \frac{p^{-\eta+1}}{1-\eta} - p p^{-\eta}, \tag{6}$$

which can be rewritten as

$$v(p) = \frac{p^{1-\eta}}{\eta - 1}. \tag{7}$$

Using the net indirect surplus function $v(p)$ and given income y, I define the utility a customer of type j gets if he buys from firm i ($i, j \in \{1, 2\}$) in period t as

$$U_{ji}^{t}(p_i^t; y) = v(p_i^t) + y + \vartheta_i - \mu_{ji} + \varepsilon_{ji}. \tag{8}$$

The utility a customer receives depends on his type and on his choices in this period. The interpretation of the first two terms in equation (8) is trivial when taken into account that p_i^t is the price firm i asks in period t. The third term ϑ_i gives utility that each customer gets for buying from firm i. This utility does not depend on the amount consumed. The fourth term in equation (8) depends on the customer type j and on the firm i where the customer will buy from. μ_{ji} gives the cost a customer faces when he switches from firm j (in the previous period) to firm i in this period. This term thus reduces the utility of the customer. In the case that the consumer does not switch ($i = j$): $\mu_{ji} = 0$.

The fifth term ε_{ji} is a random variable that gives an individual deviation in utility. This term depends both on the customer type j and on the firm i from which will be bought. For discrete choice models often a multinomial logit specification is used (e.g. Anderson et al., 1992). The logit model assumes that the terms $\varepsilon_{11}, \varepsilon_{12}, \varepsilon_{21}$ and ε_{22} are i.i.d. according to a double exponential distribution function $F(\varepsilon_{ji})$ with

$$F(\varepsilon_{ji}) = \exp\left\{ -\exp\left(-\left(\frac{\varepsilon_{ji}}{\rho_j} + \gamma \right) \right) \right\} \tag{9}$$

where γ is Euler's constant (≈ 0.577). The distribution function (9) has a mean equal to zero and a standard deviation equal to $\left(\rho_j \pi\right)/\sqrt{6}$ (Anderson et al., 1992, p. 58-60).

As explained in Van De Wielle and Verboven (2000)[8] a main criticism to the multinomial logit model is the i.i.d. assumption. By assuming i.i.d. for the

[8] In Van De Wielle and Verboven (2000) the authors look at the timing of entry in a 4 period duopoly model with outside option and without interconnection charges while using a nested logit model. In the present paper, the author tries to combine switching costs and interconnection charges in the framework of a two period duopoly model while using an ordinary logit model.

ε_{ji} it is automatically implied that the individual-specific valuations are uncorrelated across the two products, i.e. a customer's individual-specific valuation for product of firm 1 does not give information about the individual-specific valuation for products of firm 2. In reality the individual-specific valuations for both products will often be related. A possible solution to this criticism is the use of a nested logit model, see for example Anderson et al. (1992, p. 46-48) or Greene (2000, p. 865-870).

The parameter ρ_j is a measure for consumer heterogeneity of the type j consumers. If $\rho_j = 0$ the consumers are perfectly homogeneous which implies that their valuations of the two goods do not differ. Increasing values of ρ_j indicate an increasing degree of heterogeneity. The parameter ρ_j thus plays a role which can be compared to the transportation cost one has to pay in an Hotelling framework.

Using equation (8) and the following definition $v(p_i^t) = -\alpha p_i^t$ the utilities for the different options in the choice process are summarized in table 1.

Table 1: Consumer utility from choosing alternatives 1 and 2.

	Choose firm 1	Choose firm 2
Installed base firm 1	$y - \alpha p_1^t + \theta_1 + \varepsilon_{11}$	$y - \alpha p_2^t + \theta_2 + \varepsilon_{12} - \mu_{12}$
Installed base firm 2	$y - \alpha p_1^t + \theta_1 + \varepsilon_{21} - \mu_{21}$	$y - \alpha p_2^t + \theta_2 + \varepsilon_{22}$

In the remaining parts of the paper I will often make the assumptions that $\theta_i = \theta$ and $\mu_{ji} = \mu_S \; \forall i, j$.

Let λ_{ji}^t be the fraction type j consumers (they bought from firm j (=1,2) in period $t-1$) that in period t prefer to buy from firm i (=1,2). The fraction λ_{ji}^t is equal to the probability that buying from firm i gives a higher utility than buying from firm j, given that one bought from j before. Using the multinomial logit model (see above : equation (9)) and the utilities given in table 1 the probabilities can be written as

$$\lambda_{ji}^t(p_1^t, p_2^t) = \frac{\exp\left[\left(y - \alpha p_i^t + \theta_i - \mu_{ji}\right)/\rho_j\right]}{\sum_{k=1}^{2} \exp\left[\left(y - \alpha p_k^t + \theta_k - \mu_{jk}\right)/\rho_j\right]},$$

or after cancelling out the influence of the income y

$$\lambda_{ji}^t(p_1^t, p_2^t) = \frac{\exp\left[\left(\theta_i - \alpha p_i^t - \mu_{ji}\right)/\rho_j\right]}{\sum_{k=1}^{2} \exp\left[\left(\theta_k - \alpha p_k^t - \mu_{jk}\right)/\rho_j\right]}, \tag{10}$$

with $\mu_{ii} = 0$ (Anderson et al., 1992, p. 39).

Using the above stated probabilities the market shares of the two operators can be found by the following formulas

$$\alpha_1^t\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right) = \lambda_{11}^t(\tilde{p}_1^t,\tilde{p}_2^t)\alpha_1^{t-1} + \lambda_{21}^t(\tilde{p}_1^t,\tilde{p}_2^t)(1-\alpha_1^{t-1}), \qquad (11)$$

$$\begin{aligned}\alpha_1^t\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right) &= \lambda_{12}^t(\tilde{p}_1^t,\tilde{p}_2^t)\alpha_1^{t-1} + \lambda_{22}^t(\tilde{p}_1^t,\tilde{p}_2^t)(1-\alpha_1^{t-1}) \qquad (12)\\ &= 1-\alpha_1^t\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right),\end{aligned}$$

in which I used the identity $\alpha_2^t = 1-\alpha_1^t$. The identity can be used because we have a duopoly.

When the firms face in period t a constant marginal cost c_j^t $(j = 1,2)$ then the profit functions are given by

$$\pi_1^t\left(p_1^t,p_2^t,\alpha_1^{t-1}\right) = \left[\left(p_1^t-c_1^t\right)q(p_1^t)-f\right]\alpha_1^t\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right), \qquad (13)$$

$$\pi_2^t\left(p_1^t,p_2^t,\alpha_1^{t-1}\right) = \left[\left(p_2^t-c_2^t\right)q(p_2^t)-f\right]\left[1-\alpha_1^t\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right)\right], \qquad (14)$$

where $\tilde{p}_j^t = \tilde{p}_j^t(p_j^t) = v(p_j^t)$. A profit function is the product of the market share with the profit per customer. The profit per customer is the difference between the product of the profit margin per unit times the number of units, and the fixed cost of connecting a customer. In the rest of this paper the marginal cost c_j^t is replaced by the marginal cost c given in (1).

In a model of discrete choice, the consumer surplus depends on the utilities the consumers get under the different alternatives. Due to the presence of switching cost the consumer surplus will depend on the installed base the customer belonged to at the beginning of the period. The consumer surplus in period t for customers belonging to the installed base of firm j is given by

$$CS_j\left(\tilde{p}_1^t,\tilde{p}_2^t,\alpha_1^{t-1}\right) = \rho\ln\left\{\sum_{k=1}\exp\left[\frac{y+\vartheta_k-\tilde{p}_k^t-\mu_{jk}}{\rho}\right]\right\}, \qquad (15)$$

with $\mu_{jj} = 0$ (Anderson et al., 1992, p. 45).

4.2 With reciprocal access charges

This section a reciprocal access charge a is introduced. To have an economic sound reasoning the access charge is assumed to be at least $\hat{a} \equiv c_0 - c \geq 0$. If the access charge a would be smaller then $\hat{a}$ a firm could make profits on access charges by just installing a computer to call the rival's customers (Laffont et al., 1998a, p. 8).

Introducing a reciprocal access does not influence directly the choices that a customer must make because the customers do not notice the access charge in their utility function. The only influence an access charge has on the decision process of customers is indirectly via the prices that the operators ask.

Introducing a reciprocal access charge does influence the profit functions of the operators and thus their pricing decisions. It is now possible to identify three parts in a firm's profit function:

- Profit on on-net calls:

$$(p_i^t - c)\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})q(p_i^t),$$

  which is the product of a margin on the call, our fraction of customers, the probability to have an on-net call and the demand at price $\hat p_i^t$.

- Profit on originating outgoing off-net calls :

$$(p_i^t - c_1 - c_0 - a)\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})[1 - \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})]q(p_i^t),$$

  which is the product of the margin on the call, our fraction of customers, the probability to have an off-net call and the demand at price p_i^t.

- Profit on terminating incoming off-net calls:

$$(a - c_0)[1 - \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})]\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})q(p_j^t),$$

  which is the product of the margin on terminating a call, the rival's fraction of customers, the probability a rival's customer calls to our customers and the demand at price p_j^t (rival's price).

Summing the three parts and taking into account the cost f of connecting a customer gives

$$\begin{aligned}
\pi_i^t = {} & (p_i^t - c)\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})q(p_i^t) \\
& + (p_i^t - c_1 - c_0 - a)\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\left[1 - \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\right]q(p_i^t) \\
& + (a - c_0)[1 - \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})]\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})q(p_j^t) \\
& - f\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1}). \qquad (16)
\end{aligned}$$

which can be rewritten to give

$$\begin{aligned}
\pi_i^t = {} & \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\left[(p_i^t - c)q(p_i^t) - f\right] \\
& + (a - c_0)[1 - \alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})]\alpha_i^t(\hat p_i^t, \hat p_j^t, \alpha_i^{t-1})\left[q(p_j^t) - q(p_i^t)\right]. \qquad (17)
\end{aligned}$$

Equation (17) consists of two parts, the first part is the traditional profit function when no access charges are payed. The second part gives the profit or loss an operator makes on access charges. The access charge profit is the product of the margin on access charges, the market shares of both firms and the difference in quantities sold at the present prices. Equation (17) will be used in the next sections.

5 Price competition with identical firms and symmetric market conditions

In a mature market where both firms have established a network the profit function of firm i is given by equation (17). If both firms are assumed identical, the first order conditions for a symmetric equilibrium can be derived. Under a symmetric equilibrium, $p_1 = p_2 = p; \alpha_1 = \alpha_2 = \alpha = \frac{1}{2}$, and the first-order condition is

$$\frac{1}{2}\left[(p - c)q'(p) + q(p)\right] + \frac{\partial \alpha}{\partial p}\left[(p - c)\,q(p) - f\right] - \frac{1}{4}(a - c_0)\,q'(p) = 0,$$

which can be rewritten to give

$$\frac{p^* - c}{p^*} = \frac{1 + 2f\frac{\lambda_{11}\lambda_{12}}{\rho} + \eta\frac{(a-c_0)}{2p^*}}{\eta + 2\frac{\lambda_{11}\lambda_{12}}{\rho}p^* q(p^*)}, \tag{18}$$

where under symmetry

$$\frac{\lambda_{11}\lambda_{12}}{\rho} = \frac{\exp\left(\frac{-\mu_S}{\rho}\right)}{\rho\left[1 + \exp\left(\frac{-\mu_S}{\rho}\right)\right]^2}. \tag{19}$$

With exception of the term $\frac{\lambda_{11}\lambda_{12}}{\rho}$ the above formula (18) is equal to equation (6) from Laffont et al. (1998a, p. 9). Laffont et al. (1998a) have the parameter σ where I have the term $\frac{\lambda_{11}\lambda_{12}}{\rho}$. In their paper σ is an index of substitutability and as such has an interpretation that is similar to our interpretation of $\frac{1}{\rho}$. The difference is thus formed by the presence of $\lambda_{11}\lambda_{12}$ which are due to the switching cost μ_S[9].

The presence of $\lambda_{11}\lambda_{12}$ has two important consequence. First, the term $\frac{\lambda_{11}\lambda_{12}}{\rho}$ which replaces the substitutability term σ never becomes very large as long as a positive switching cost is present and regardless of the value of ρ. More precisely

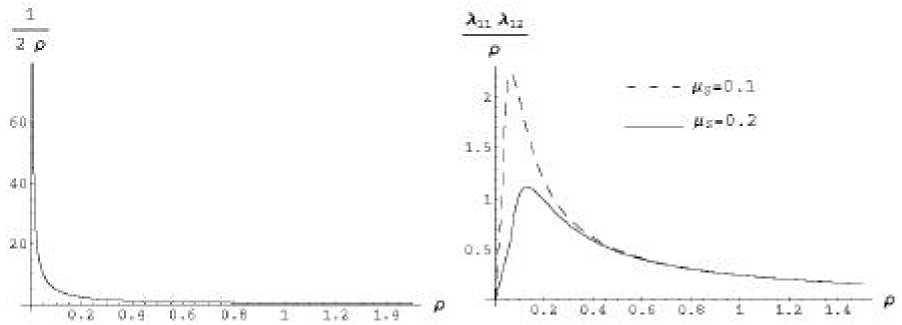
$$\lim_{\rho \to +\infty}\frac{\lambda_{11}\lambda_{12}}{\rho} = 0 \text{ and } \lim_{\rho \to 0}\frac{\lambda_{11}\lambda_{12}}{\rho} = 0 \tag{20}$$

(see appendix D for a proof of the limits). The importance may not be underestimated as Laffont et al. (1998a) show in their proposition 1 that a unique symmetric equilibrium exists for the access charge and/or the substitutability of the networks not to large. In other words they only find an equilibrium is amongst other things the parameter σ does not become to large. The limits in (20) show that I do not encounter such a problem. The difference between using or not using switching costs is illustrated in figure 2. Without switching costs (figure 2 (a)) $\frac{\lambda_{11}\lambda_{12}}{\rho} = \frac{1}{2\rho}$ goes to infinity for small values of ρ which makes it impossible to calculate equilibrium prices. Using switching costs (figure 2 (b)) the term $\frac{\lambda_{11}\lambda_{12}}{\rho}$ attains a maximum value in the neighbourhood of $\rho = 0$ but does not go to infinity and equilibrium calculations remain possible.

Second, the higher the switching cost μ_S, the lower the maximum value that $\frac{\lambda_{11}\lambda_{12}}{\rho}$ can attain as a function of ρ. In figure 2 (b) the function $\frac{\lambda_{11}\lambda_{12}}{\rho}$, as

[9] Without switching cost ($\mu_S = 0$) the function $\frac{\lambda_{11}\lambda_{12}}{\rho} = \frac{1}{2\rho}$ which is similar to the definition of $\sigma = \frac{1}{2t}$ (Laffont et al., 1998a, p. 7).

Figure 2: Degrees of substitutability



(a) No Switching Costs (b) With Switching Costs

defined in (19), is given once for $\mu_S = 0.1$ and once for $\mu_S = 0.2$. The influence of μ_S is clear. In the limit this maximum value of $\frac{\lambda_{11}\lambda_{12}}{\rho}$ will become 0 if μ_S goes to infinity. This result implies that even when customers are very homogeneous ($\rho \to 0$), it is still possible to let the market behave as a market with perfectly heterogeneous customers ($\rho \to +\infty$) as long as the switching costs are set high enough.

In the light of the two points given above, it is possible to formulate the following proposition which is a reformulation of proposition 1 in Laffont et al. (1998a).

Proposition 1 In a symmetric market situation and for access charge a close to the marginal cost c_0, there exits a unique symmetric equilibrium which is characterized by $p_1 = p_2 = p^*$ and given by

$$\frac{p^* - c}{p^*} = \frac{1 + 2\{\frac{\lambda_{11}\lambda_{12}}{\rho} + \eta\frac{(a - c_0)}{2p^*}}{\eta + 2\frac{\lambda_{11}\lambda_{12}}{\rho}p^*q(p^*)},$$

as long as the switching cost μ_S is set high enough.

6 Price competition with different installed bases and market growth

The above found results are for a situation in which both firms are identical and face symmetric market conditions. In real world the situations, different firms are not symmetric, nor identical. A number of asymmetries and di¤erences are easily identi…ed:

- ² Di¤erent technologies which leads to di¤erent marginal costs.
- ² Di¤erent coverage which a¤ects the scale of operation of the various …rms.
- ² Non-reciprocal access charges.
- ² Di¤erences in installed base.

I will focus on the last mentioned asymmetry: di¤erences in installed base or in other words di¤erences in market share at the beginning of a competition period. As the probability of having …rms with exactly the same market share is very small, a …rm will almost always have to ask the question : "From which …rm will the old customers buy this period ?". This question is especially important with entry. In every industry and thus also in telecommunications an entrant is faced with rivals who have a captured installed base while the …rm itself has no customers from previous periods.

A related problem is the issue of market growth: Where do the new customers buy ? New customers are by de…nition not a¤ected by switching costs[10]. As an assumption I de…ne market growth as the percentage increase in customers that are going to e¤ectively buy from one of the …rms.

6.1 Model adaptations for numerical analysis

Some adaptations are needed to allow for the two issues mentioned above. Introducing market growth requires two changes. First a new extra row has to be added to table 1 which becomes:

Table 2: Consumer utility under constant elasticity demand and market growth

	Choose …rm 1	Choose …rm 2
Installed base …rm 1	$y + Ã ¡ \overline{p_1} + "_{11}$	$y + Ã ¡ \overline{p_2} + "_{12} ¡ ¹_{12}$
Installed base …rm 2	$y + Ã ¡ \overline{p_1} + "_{21} ¡ ¹_{21}$	$y + Ã ¡ \overline{p_2} + "_{22}$
New Customers	$y + Ã ¡ \overline{p_1} + "_{01}$	$y + Ã ¡ \overline{p_2} + "_{02}$

The new row accounts for those customers that are new in the market: their utility depends on the …rm they are going to buy from. The probabilities that correspond with table 2 are given by equation (10) taking into account that new customers do not face a switching cost: $¹_{01} = ¹_{02} = 0$. Second, introducing market growth requires changing the de…nition of market shares. Using as short

[10] New customers often have to pay entry costs. To simplify the analysis I will assume here that these entry costs are zero regardless from which …rm a customer wants to buy.

notation $\alpha_i^t = \alpha_i^t(p_i^t; p_j^t; \alpha_i^{t-1})$ and $\lambda_{ij}^t = \lambda_{ij}^t(p_i^t; p_j^t)$ and g as the market growth rate, the market shares are given by

$$\alpha_i^t = \lambda_{1i}^t \frac{\alpha_1^{t-1}}{1+g} + \lambda_{2i}^t \frac{(1-\alpha_1^{t-1})}{1+g} + \lambda_{0i}^t \frac{g}{1+g}, \text{ with } i \in \{1; 2\}. \tag{21}$$

This equation can be derived as follows. At the end of the previous period two firms devided the market. This period the market grows by g%. The total market thus becomes $(1 + g)$ times the previous market. Deviding the previous market shares and the fraction of new customers by $(1 + g)$ rescales the market again to 100%. When $g = 0$ the equation (21) simplifies to equations (11) and (12). Allowing the firms to have different initial market shares does not require extra changes to the model. The formulas for the profit margins on the different type of calls do not change under asymmetry. Firm i must thus optimize equation (17) in each period using the new definitions for market share given above.

To optimally study the effects of different installed bases and of different rates of market growth it is useful to look at a multi-period model. In a multi-period model the results from one period influence the next ones through changes in market shares. Optimally a firm will take these influences into consideration. The general optimization problem of firm i for n periods and using a discount factor δ is:

$$\max_{p_i^t; p_i^{t+1}; \ldots; p_i^{t+n}} \Pi_i = \sum_{l=0} \delta^l \pi_i^{t+l}, \tag{22}$$

where π_i^{t+l} is defined as in (17) and where customers are assumed to be myopic[11]. Solving the optimization problem requires simultaneous determining the prices for all the n periods. This involves solving a set of $N \times n$ equations (N is the number of firms in the industry). Due to the complexity of this equations it is not possible to solve for a solution analytically even for the case where $n = 2$[12]. To be able to give some insights for the asymmetric case I used numerical computations to find the optimal prices for a two period model. The followed procedure is explained in the next subsection.

6.2 Numerical analysis

The ultimate aim of this modelling of the telecommunications sector is twofold : first, getting observed market shares using realistic parameter values and second, the opposite, calibrating the model to get realistic parameter values from the observed market shares and prices. In this stage, a numerical model is used to study the effects of different rates of market growth and of different installed bases in a two period duopoly model with identical firms.

[11] Myopic customers only consider their present utility when making a choice between the different operators.

[12] Van De Wielle and Verboven (2000, p. 8) give an analytical solution for the symmetric case in a nested logit model. Symmetry allows for a number of simplifying assumptions.

The numerical computations are performed in MATLAB. The model calculates the optimal …rst and second period prices for both …rms under varying values of the installed bases and of the market growth. The optimal prices are found by solving for the highest pro…t for both …rms taking into account that the …rms are not allowed to price discriminate between new and old customers in case of market growth. The prices in combination with the initial market shares (installed base of the …rms) are then used to calculate the new market shares from which the pro…ts follow. The …rst and second period prices are determined simultaneously because …rms must account for the e¤ects their pricing behavior has on their future pro…tability. These cross period e¤ects are caused by the presence of the consumer switching costs who make market share a valuable asset and thus imply an dynamic element for a model. Customers themselves are assumed to be myopic. This last assumption is restrictive in a sense that a rational customer can be expected to look at his future utility, but the assumption does capture the idea that …rms are usually the better informed party (at least concerning their own pricing decisions) in the market.

More practically, the computation procedure is the following. A starting point are the initial values for the …rst period price set by …rm 2, p_2^1, and the second period prices of both …rms, p_1^2 and p_2^2. From these prices the best-response price of …rm 1, p_1^{1*}, is then calculated. This best-response price maximizes the present and future pro…ts of …rm 1 given the other prices. A second step then calculates the best-response of …rm 2 in the …rst period, p_2^{1*}, to the prices p_1^{1*}, p_1^2 and p_2^2. A third and fourth step are to calculate p_2^{2*} and p_1^{2*} given the …rst period best-response prices. After step four which we start again with calculating the …rst period best-response of …rm 1 to all the other prices. This iterative procedure takes place until convergence is reached, i.e. the best-response prices do not di¤er signi…cantly anymore from there previous values.

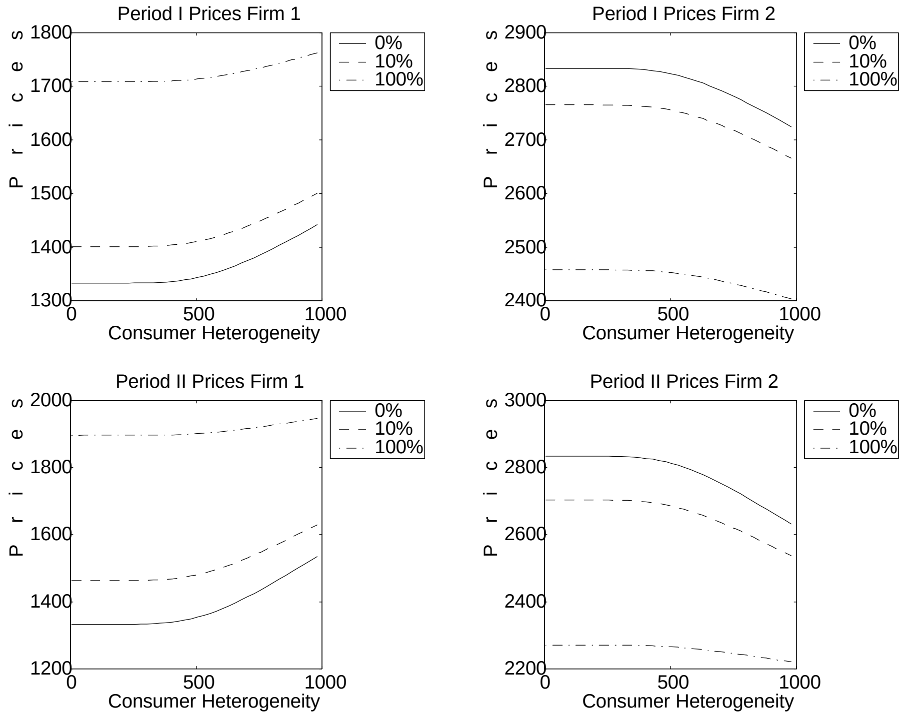
The next session gives the results of the model. Table 4 in appendix E contains the parameter values used in the computations.

6.3 Numerical analysis: results

In this numerical analysis I look at two parameters of interest: the market growth which takes values of respectively 0%, 10% and 100%, and the installed base of the two …rms. I de…ne …rm 1 to be the incumbent …rm and its installed base takes the values 100%, 80%, 60% and 50%. Firm 2, de…ned to be the entrant, then of course has the following initial market shares: 0%, 20%, 40% and 50%. The calculations for the di¤erent rates of market growth are made with …rm 1 having an installed base equal to 100% and the calculations for the di¤erent possible installed bases are made with a market growth of 10%. For all the possible parameter settings I vary the degree of consumer heterogeneity.

In this section I will look at the optimal prices. The results are given in …gure 3 for variable market growth and in …gure 4 for variable installed bases. Appendix F contains the corresponding results for …nal market shares and pro…ts. The explanation with the lasts results in the appendix is similar to the one for prices.

Figure 3: Variable Market Growth: Prices



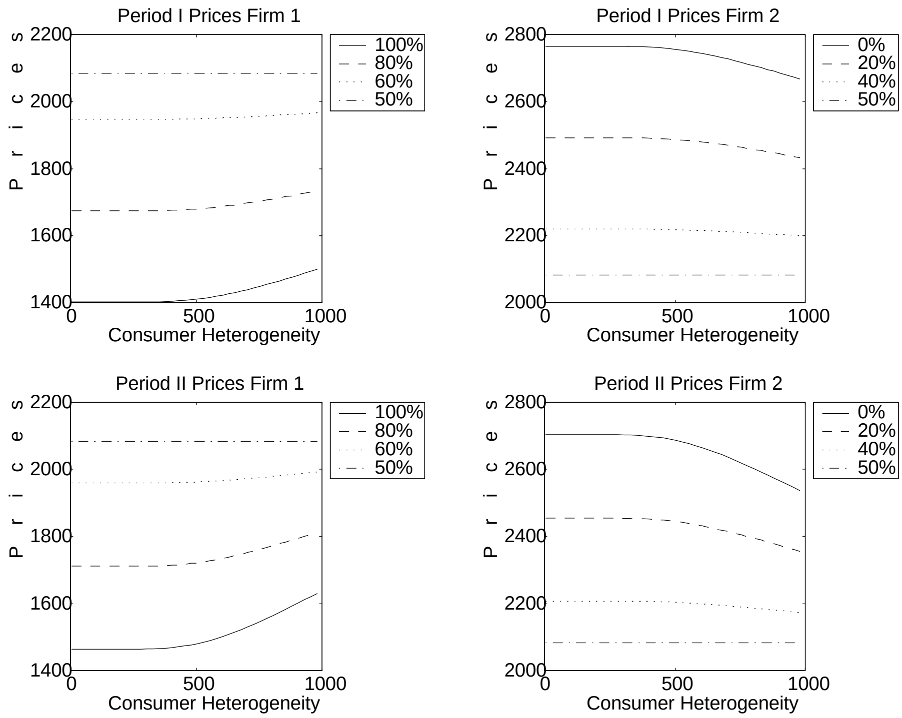
When looking at …gures 3 and 4, there are a number of issues that have to be explained because the pricing behavior is not what we normally expect. A …rst issue is the seemingly strange pricing behavior of the entrant (…rm 2) which prices higher than the incumbent (…rm 1). The entrant does not try to beat the incumbent. A possible explanation can be a combination of a high value for the elasticity ´[13] with switching costs and access charges. The switching costs lock customers in and thus give market power. Access charges are received by the …rm that sets the highest price and paid by the …rm that sets the lowest price. The total amount of access charge paid depends thus on the price di¤erence but not only on that price di¤erence. The market shares of both …rms play a role also (see section 4.2). The assumption ´ > 1 basically means that the customers are very sensitive to price changes.

Normally an entrant is expected to undercut the incumbent in order to gain market share. In this model the entrant does not undercut. A possible explanation is the following. The price changes needed to attract customers from the incumbent have to be big enough to cover the switching costs that the customers face. Thus in order to win the majority of the consumers the

[13] The assumption ´ > 1 is made to avoid convergence problems (See e.g. La¤ont et al., 1998a, p. 7).

entrant must undercut his rival by an amount at least equal to the switching cost $^{1}{}_{S}$. The reaction of the incumbent will be to undercut his rival. A price war would thus be the outcome. A price war that the entrant can not win because both …rms have the same marginal cost and the incumbent has the advantage of locked in customers. In the model the entrant might follow another strategy. By charging a high price the entrant exploits the small number of customers that he still attracts[14] and he probably makes pro…ts on access charges. Further research is needed to determine what the exact causes are of the strange behavior of the entrant.

Figure 4: Variable Installed Base: Prices



A second issue that appears in both …gures is the incumbent (…rm 1) charging a lower price for homogeneous customers then for heterogeneous customers and the entrant (…rm 2) doing exactly the opposite. The explanation probably has to be sought with the switching costs present in the model. If consumers are very homogeneous, then switching costs are a way for the …rms to di¤erentiate. The incumbent knows that asking a high price will make him loose most of his customers to the entrant. Therefore he will be inclined to set a low price. The entrant on the other hand knows that with homogeneous customers few will make the switch to his product (and he can not undercut, see

[14] Remember that due to the characteristics of the logit model there is always a probability that a customer switches.

above). He might thus be inclined to exploit the few customers he gets even more. If customers get more heterogeneous, the entrant has a bigger chance of attracting new customers. The number of customers that want to leave the incumbent is positive function of the degree of heterogeneity of the customers. The entrant can strengthen this positive e¤ect by lowering his price. For the incumbent the reasoning is the opposite. More heterogeneous customers means that an increase of his price will not make him loose as much customers as with homogeneous customers. Probably access charge issues will play are role here too. Further research has to be conducted to determine the exact in‡uence of this access charges.

Studying …gure 3 two extra observations can be made. First, higher market growth induces the incumbent to charge higher prices and induces the entrant to charge lower prices. The entrant lowers his prices because the higher the market growth, the bigger the amount of not locked in customers for which he can compete on equal grounds with the incumbent. It will be bene…cial for him to ask a lower price to a greater number of customers than charging a high price to a very small number of customers. The incumbent …rm sees the percentage of locked in customers decrease which is comparable to having more a heterogeneous group of customers. It becomes more bene…cial for the incumbent to exploit his group of locked in customers then to enter a price war with the entrant over the new customers. Remember that price discrimination is not allowed which implies that a lower price a¤ects all the customers. Asking a higher prices might have a positive secondary e¤ect for the incumbent: it lowers his access de…cit. Second, …gure 3 shows that the incumbent charges higher prices in the second period than in the …rst period for comparable values of market growth. The entrant does the opposite. The only situation in which the …rst and second period prices are equal is under a 0% market growth for homogeneous consumers. The higher second period prices for the incumbent might be explained as follows: without the in‡uence of future periods it is more pro…table to exploit the current installed base of customers. The market shares at the end of the second period do not have a future value anymore. The absence of future periods allow the entrant to charge a lower price because he does not have to fear for a tougher competition in the next periods when he takes away market share of the incumbent. At 0% market growth and homogeneous consumers the prices are identical in both periods because both periods are identical. Due to the low …rst period price of the incumbent and the high …rst period price of the entrant, the incumbent …rm succeeds in keeping the whole market locked in (see …gure 5 in appendix F).

Studying …gure 4, gives some extra insights. First, it is obvious that when …rms start with equal installed bases (each 50% market share) they end up doing exactly the same because all the other model parameters are also identical. Second, the highest price di¤erences between …rm 1 and …rm 2 are found when …rm 1 has 100% market share which implies that …rm 1 tries to protect its market. I can think of two possible explanations for the behaviour of the incumbent. First, it might be more pro…table to have a low price from a large number of customers then a high price from a smaller number of customers. The second possible explanation is that the incumbent only has to pay a small access deficit if he succeeds in keeping almost 100% market share. Having almost the complete market implies that there are few customers with the rival to which the own customers can call. When customers are perfectly homogeneous, the incumbent will succeed in keeping almost a 100% market share (see figure 8 in appendix F) but not the entire market because a small fraction of the new customers prefers to buy from the entrant. A third and finally insight, a smaller installed base for the incumbent brings higher incumbent prices and lower entrant prices. An explanation could be that an incumbent finds its installed base less worth fighting for if it gets smaller while the entrant gets an installed base that rises in value. The more equal the market shares the more equal the prices charged by incumbent and entrant.

7 Concluding remarks

This paper gives a model for price competition under consumer switching costs in a network setting with interconnection charges. The model is used to look at some issues in the telecommunications sector, more specifically: entry and growth. Entry has occured in this sector in the past and will occur in the future. The model was developed in such a way it can be used to simultaneously study two problems that an entrant faces: interconnection issues and the problem of pursuading locked in customers to leave the incumbent firm and to buy from the entrant. The growth rate of the market influences both the incumbent as the entrant. The model developed in this paper distinguished itself from previous models in the literature by using a multinomial logit model to differentiate the customers. The logit model is used in combination with a constant elasticity demand and consumer switching costs.

When working with identical firms, standard literature results can be obtained by setting the switching costs to zero. If the switching costs differ from zero, proposition 1 showed that it is possible to get equilibria both in the case of homogeneous and of heterogeneous consumers. Numerical computations had to be used to find the equilibrium results for the case where both firms face asymmetric market situations. The main results from the numerical analysis were

- The entrant is sometimes better of by charging a higher price than the incumbent.
- The entrant charges his highest prices to homogeneous consumers, while the incumbent charges homogeneous consumers his lowest price.
- A higher market growth lowers the price of the entrant and raise the price of the incumbent.
- The incumbent will charge higher prices in the second period then in the first period. The entrant will charge lower prices in the second period then in the first period.

The explanation for these results might be found in a combination of switching costs and interconnection charges. One must also bear in mind that the elasticity of demand is high in the present numerical calculations. It will be a …rst extension to the paper to rework the model so that the in‡uence of the elasticity of demand will become clearer. As most readers will have noticed, the present paper leaves room for some other extensions. Giving an exhaustive list of all possible extensions would lead us to far but the extensions mentioned below are likely topics of my research in the near future.

A …rst possible extension is adding more periods to the model. More periods will allow to study the path followed to a more steady state equilibrium. It might be possible to determine the number of periods that have an in‡uence on the prices of the present period. Obviously, the role of a discount factor will be important here. A second extension is allowing for none-reciprocal access charges. None-reciprocal access charges can prevent or promote pro…table entry depending on the values of the access charges. Determining in which range of access charges, which e¤ect on entry will occur is useful information which can be used by a regulator to get to a desired market outcome. Adding an outside option to the model can be a third extension. An outside option means that customers get an extra choice: not buying at all. In the mobile telecommunications sector one can think of customers who decide to keep using their …xed phone and do not buy a mobile. Having the option of staying out of the market will allow to look at the attractiveness of the market as a whole.

The above mentioned extensions are all theoretical. A fourth and equally important extension is trying to check if the theory can be con…rmed by empirical research. The model allows for the introduction of more asymmetries between the …rms and between the di¤erent periods. Using real world data on market shares and prices, it must be possible to obtain realistic values for the parameters.

A Key points in the liberalization

The following table contains some key points in the liberalization process as required by the European Union.

Table 3: Liberalization : Key Points

1988	Technical Equipment
1990	Value Added Services (no voice telephony)
1990	Satellite Communication
1994	Mobile Communication
1998	Public Voice Telephony and Public Telecommunication Networks
2000	Number Portability

Source: Sociaal-Economische Raad Van Vlaanderen (1996)

B Unit demand and reciprocal access charges

Lemma 1 Using a reciprocal access charge in a discrete choice model with balanced calling patterns and unit demand has no influence on the price decisions taken by the firms.

Proof. Using balanced calling patterns the probability of calling a certain network is equal to the fraction of consumers that belong to that network. After introducing reciprocal access charges the firm's profit function consists of the three terms below (see section 4.2). The marginal costs are defined as in 1.

Under unit demand $q(p_i^t) = 1$ and $q(p_j^t) = 1$, which allows to rewrite equation (16) as

$$\pi_i^t = (p_i^t - c)\alpha_i^t\alpha_i^t + (p_i^t - c + c_0 - a)\alpha_i^t(1 - \alpha_i^t) + (a - c_0)(1 - \alpha_i^t)\alpha_i^t - f\alpha_i^t$$

$$\Leftrightarrow \pi_i^t = (p_i^t - c)\alpha_i^t(\alpha_i^t + 1 - \alpha_i^t) - f\alpha_i^t$$

$$\Leftrightarrow \pi_i^t = (p_i^t - c - f)\alpha_i^t.$$

The last equation is equal to the profit function (13) or (14) and it is thus shown that adding reciprocal access charges gives no extra information in case of discrete choice under unit demand. ■

C Ramsey prices

In this appendix I will take a closer look at the optimization problem defined by equations (??) and (??). Concerning the Ramsey prices I use the following lemma:

Lemma 2 In our discrete choice model the Ramsey price p^R can be found as the solution to the budget constraint

$$(p^R - c)q(p^R) = f,$$

if $\alpha_1^{t-1} = \alpha_2^{t-1} = \frac{1}{2}$ or if $\mu_S = 0$.

Proof. Remember the optimization problem:
Maximize

$$W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1}) = \alpha_1^{t-1} CS_1(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1}) + (1 - \alpha_1^{t-1}) CS_2(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})$$

subject to

$$BC(p_1^t; p_2^t) = \alpha_1^t \left(p_1^t - c\right) q(p_1^t) + (1 - \alpha_1^t)\left(p_2^t - c\right) q(p_2^t) - f = 0.$$

Which gives the following Lagrangian function:

$$\mathcal{L}(p_1^t; p_2^t; \alpha_1^{t-1}) = W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1}) + \beta BC(p_1^t; p_2^t).$$

The first order conditions of the Lagrangian function can be written as

$$\frac{\partial \mathcal{L}(p_1^t; p_2^t; \alpha_1^{t-1})}{\partial p_i^t} = \frac{\partial W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_i^t} + \beta \frac{\partial BC(p_1^t; p_2^t)}{\partial p_i^t} = 0, \text{ with } i \in \{1, 2\} \tag{23}$$

$$\frac{\partial \mathcal{L}(p_1^t; p_2^t; \alpha_1^{t-1})}{\partial \beta} = BC(p_1^t; p_2^t) = 0 \tag{24}$$

Considering the definition of the consumer surplus as given in (15) the partial derivatives can be written as

$$\frac{\partial CS_i(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_i^t} = -\lambda_{ii} p_i^{-\eta},$$

$$\frac{\partial CS_i(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_j^t} = -\lambda_{ij} p_j^{-\eta}.$$

Which gives

$$\frac{\partial W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_1^t} = -\left[\alpha_1^{t-1}\lambda_{11} + (1 - \alpha_1^{t-1})\lambda_{21}\right] p_1^{-\eta}, \tag{25}$$

$$\frac{\partial W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_2^t} = -\left[\alpha_1^{t-1}\lambda_{12} + (1 - \alpha_1^{t-1})\lambda_{22}\right] p_2^{-\eta}, \tag{26}$$

and

$$\frac{\partial BC(p_i^t; p_j^t)}{\partial p_i^t} = \left[\lambda_{1i}\alpha_1^{t-1} + \lambda_{2i}(1 - \alpha_1^{t-1})\right] p_i^{-\eta} \left(1 - \frac{(p_i - c)\eta}{p_i}\right) + \frac{\lambda_{1i}\lambda_{2i}}{\rho}\left[(p_j - c)p_j^{-\eta} - (p_i - c)p_i^{-\eta}\right] \tag{27}$$

where

$$\lambda_{ij}(p_1,p_2)=\frac{\exp\left\{\left[(\eta-1)v-p_j^{1-\eta}-(\eta-1)\mu_{ij}\right]/[(\eta-1)\rho]\right\}}{\sum_{k=1}^{2}\exp\left\{\left[(\eta-1)v-p_k^{1-\eta}-(\eta-1)\mu_{ik}\right]/[(\eta-1)\rho]\right\}}$$

If now $\alpha_1^{t-1}=\frac{1}{2}$, the equations (25), (26) and (27) reduce to

$$\frac{\partial W(\hat{p}_1^t,\hat{p}_2^t,\alpha_1^{t-1})}{\partial p_1^t} = -\frac{[\lambda_{11}+\lambda_{21}]}{2}p_1^{-\eta}, \tag{28}$$

$$\frac{\partial W(\hat{p}_1^t,\hat{p}_2^t,\alpha_1^{t-1})}{\partial p_2^t} = -\frac{[\lambda_{12}+\lambda_{22}]}{2}p_2^{-\eta}, \tag{29}$$

$$\frac{\partial BC(p_1^t,p_2^t)}{\partial p_1^t} = \frac{[\lambda_{11}+\lambda_{21}]}{2}p_1^{-\eta}\left(1-\frac{(p_1-c)\eta}{p_1}\right) + \frac{\lambda_{11}\lambda_{21}}{\rho}\left[(p_2-c)p_2^{-\eta}-(p_1-c)p_1^{-\eta}\right], \tag{30}$$

$$\frac{\partial BC(p_1^t,p_2^t)}{\partial p_2^t} = \frac{[\lambda_{12}+\lambda_{22}]}{2}p_2^{-\eta}\left(1-\frac{(p_2-c)\eta}{p_2}\right) + \frac{\lambda_{12}\lambda_{22}}{\rho}\left[(p_1-c)p_1^{-\eta}-(p_2-c)p_2^{-\eta}\right]. \tag{31}$$

Due to the similarities between equations (28) and (29) and between (30) and (31) it follows that $p_1=p_2=p$, applying this result to equation (24) gives

$$\frac{\lambda_{1i}+\lambda_{2i}}{2}\left[2(p-c)q(p)\right]-f=0,$$

with $\lambda_{1i}+\lambda_{2i}=1$ if $p_1=p_2=p$, thus

$$(p-c)q(p)=f,$$

which is the budget constraint and which proves the first part of our proposition.

If now $\alpha_1^{t-1}\neq\frac{1}{2}$ but $\mu_S=0$, the distinction between the two consumer surplus functions disappears: $CS_1(\hat{p}_1^t,\hat{p}_2^t,\alpha_1^{t-1})=CS_2(\hat{p}_1^t,\hat{p}_2^t,\alpha_1^{t-1})$. The equations (25), (26) and (27) now reduce to

$$\frac{\partial W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_1^t} = -\lambda_1 p_1^{-\eta}, \tag{32}$$

$$\frac{\partial W(\hat{p}_1^t; \hat{p}_2^t; \alpha_1^{t-1})}{\partial p_2^t} = -\lambda_2 p_2^{-\eta}, \tag{33}$$

$$\begin{aligned}\frac{\partial BC(p_1^t; p_2^t)}{\partial p_1^t} &= \lambda_1 p_1^{-\eta}\left(1 - \frac{(p_1 - c)\eta}{p_1}\right) \\ &\quad + \frac{\lambda_1\lambda_2}{\rho}\left[(p_2 - c)p_2^{-\eta} - (p_1 - c)p_1^{-\eta}\right]\end{aligned} \tag{34}$$

$$\begin{aligned}\frac{\partial BC(p_1^t; p_2^t)}{\partial p_2^t} &= \lambda_2 p_2^{-\eta}\left(1 - \frac{(p_2 - c)\eta}{p_2}\right) \\ &\quad + \frac{\lambda_1\lambda_2}{\rho}\left[(p_1 - c)p_1^{-\eta} - (p_2 - c)p_2^{-\eta}\right]\end{aligned} \tag{35}$$

with

$$\lambda_i^t = \frac{\exp\left[(v - \hat{p}_i^t)/\rho\right]}{\exp\left[(v - \hat{p}_1^t)/\rho\right] + \exp\left[(v - \hat{p}_2^t)/\rho\right]} \text{ and } i \in \{1; 2\}.$$

Equations (32), (33), (34) and (35) imply $p_1 = p_2 = p$ and thus $\lambda_1 = \lambda_2 = \frac{1}{2}$. Equation (24) can now be written as

$$(p - c)\, q(p) = f,$$

which is the budget constraint if both firms charge the same price and which proves the second part of the proposition. ■

D Limits

The limits of

$$\frac{\lambda_{11}\lambda_{12}}{\rho} = \frac{\exp\left(\frac{-\mu_s}{\rho}\right)}{\rho\left[1 + \exp\left(\frac{-\mu_s}{\rho}\right)\right]^2},$$

for $\rho \to \infty$ and $\rho \to 0$ with $\mu_s > 0$ are calculated as follows:

- $\rho \to \infty$:

$$\lim_{\rho \to +\infty} \frac{\lambda_{11}\lambda_{12}}{\rho} = \lim_{\rho \to +\infty} \frac{\exp\left(-\frac{\mu_S}{\rho}\right)}{\rho\left[1+\exp\left(-\frac{\mu_S}{\rho}\right)\right]^2}$$

$$= \frac{\exp\left(-\frac{\mu_S}{+\infty}\right)}{+\infty\left[1+\exp\left(-\frac{\mu_S}{+\infty}\right)\right]^2}$$

$$= \frac{\exp(0)}{+\infty\,[1+\exp(0)]^2}$$

$$= \frac{1}{+\infty\,[1+1]^2} = 0$$

• $\rho \to 0$:

Make the substitution $u = \frac{\mu_S}{\rho} \Rightarrow \rho = \frac{\mu_S}{u}$, then for a fixed value μ_S if $\rho \to 0$ then $u \to +\infty$:

$$\lim_{\rho \to 0} \frac{\lambda_{11}\lambda_{12}}{\rho} = \lim_{u \to \infty} \frac{\exp(-u)}{\frac{\mu_S}{u}\,[1+\exp(-u)]^2}$$

$$= \lim_{u \to +\infty} \frac{\exp(-u)}{\frac{\mu_S}{u}} \lim_{u \to +\infty} \frac{1}{[1+\exp(-u)]^2}$$

$$= \lim_{u \to +\infty} \frac{u}{\mu_S \exp(u)} \cdot \frac{1}{(1+0)^2}$$

applying L'Hôpital gives

$$\lim_{\rho \to 0} \frac{\lambda_{11}\lambda_{12}}{\rho} = \lim_{u \to +\infty} \frac{1}{\mu_S \exp(u)} = \frac{1}{+\infty} = 0.$$

E Inputs for numerical analysis

The following table contains the inputs that were used during the numerical analysis. I want to point out to the reader that these values have been chosen for the analysis in this paper. Their true market values still have to be determined.

Table 4: Inputs Numerical Analysis.

^1S	1500	Consumer switching costs
v	10000	Basic utility of being a customer
c	800	Total Marginal Cost
c_0	200	Marginal Cost of the Local Loop
c_1	400	Long Distance Marginal Costs
´	2.5	Number Portability
a	1100	Interconnection or Access Charge
f	0	Fixed cost of connecting one customer
±	1	Discount value

F Extra numerical results

Figure 5: Variable Market Growth: Market Shares

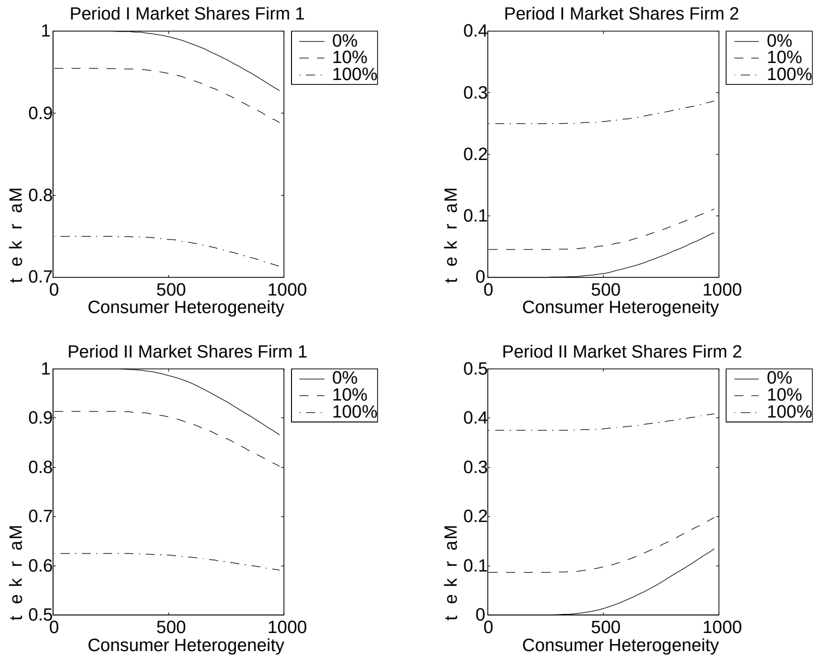


Figure 6: Variable Market Growth: First and Second Period Pro…ts

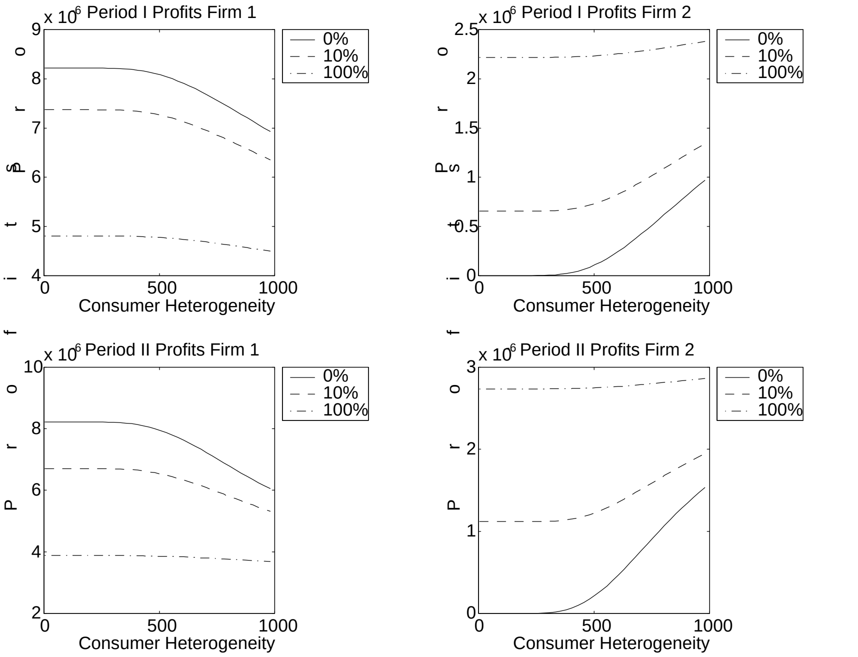


Figure 7: Variable Market Growth: Total Pro…ts

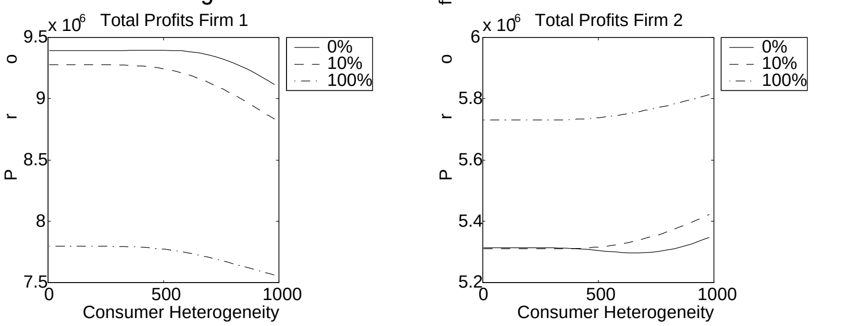


Figure 8: Variable Installed Base: Market Shares

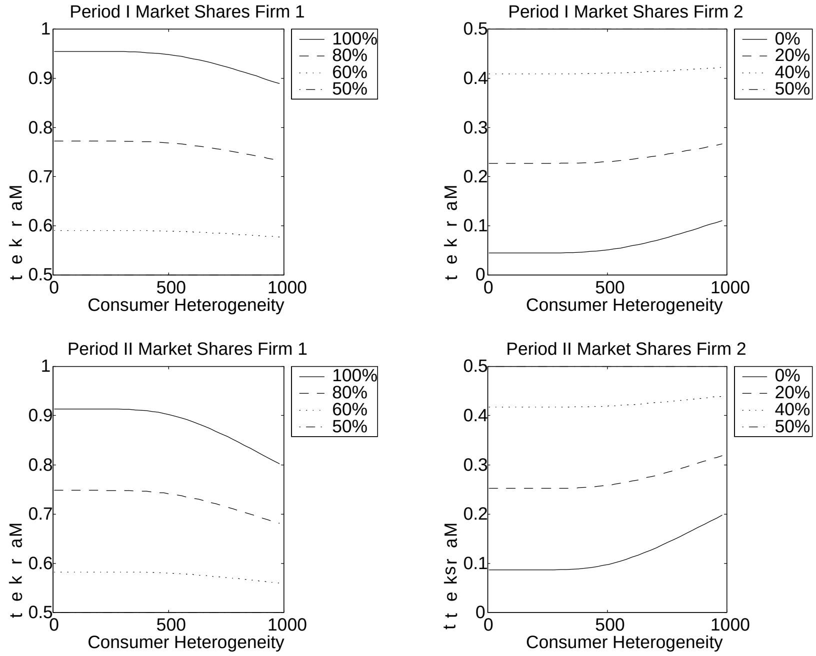


Figure 9: Variable Installed Base: First and Second Period Profits

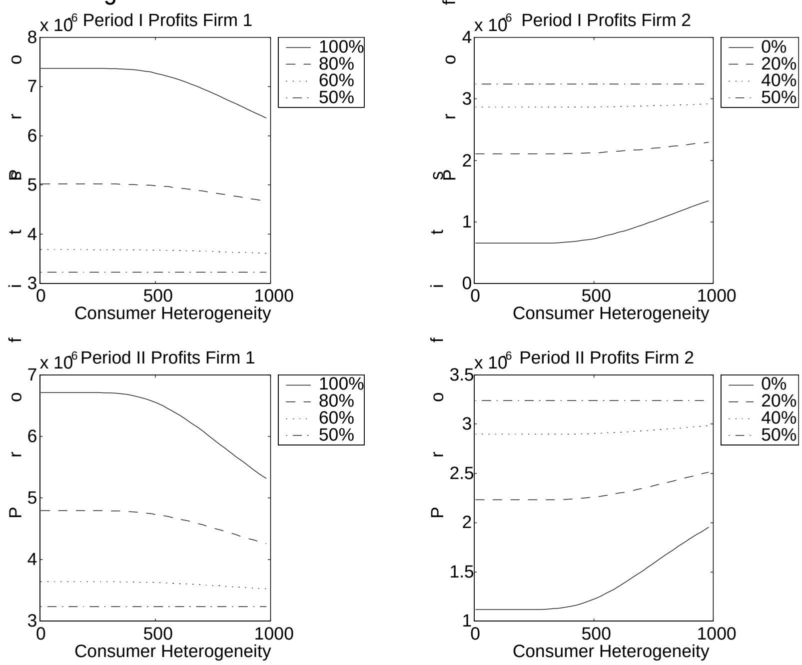
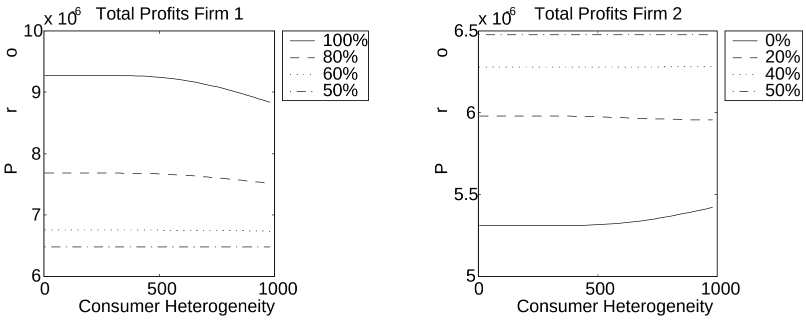


Figure 10: Variable Installed Base: Total Pro…t



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