Essays on Economics of Network Industries: Mobile Telephony

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Contents

Chapter 1

Introduction

During the last two decades, network industries have been going through a tremendous transformation. Many countries worldwide started to liberalize traditionally monopolized network industries, such as telecommunications, electricity, railways and the airline industry. Technological progress stimulated the development of new industries and products, a decline in production costs and a rise in quality. New technologies, such as personal computers, the Internet, mobile telephony, CD players and many others experienced dramatic growth rates. For instance, at the end of 2004, about 83% of EU citizens were connected to mobile telephone networks, just one decade after the startup of digital cellular services. Also Internet penetration in many countries worldwide has exceeded 60% of households within one decade.

This transformation process and the establishment of new industries have a critical impact on lifestyle, working methods and the economy as a whole, through the rising share in GDP and the creation of new jobs. It is extremely important to understand the mechanisms, which determine the competition and consumers' behavior in network industries. In this way, an appropriate support could be provided for the regulatory and competition policy, which should facilitate the creation of competitive and innovative network industries. The key determinants of equilibrium outcomes in many network industries, such as computers, the Internet and telecommunications, are network effects and consumer switching costs.

Network effects and switching costs introduce differences in the nature of competition, such as 'competition for the market' or 'life-cycle competition', as compared to traditional industries. When switching costs are present, firms enjoy ex post market power over their own consumers. Network effects extend this power to future generations of buyers. Eventually, socially inefficient market outcomes are possible, such as unreasonable high prices, high industry concentration, entry barriers, standardization on inferior technology. Thus, switching costs and network effects have been a central issue in many antitrust cases, for instance, in the US and the European Microsoft case. The regulatory and competition policy must be appropriately adjusted in order to deal with network technologies, where the dynamic perspective of competition becomes critical for the final assessment. Apart from theoretical justifications, there is also a crucial role of empirical studies, which may provide decisive arguments on whether or not policy intervention is needed.

There is a large body of theoretical literature on switching costs and network effects. Their impacts on consumer choice and competition are well known (see Farrell and Klemperer (2004)). However, there are still some interesting questions, which may be addressed by economic theory. Empirical research is even more in demand. Network externalities and switching costs in the mobile telecommunications industry are the key focus of this dissertation. In this chapter, I shortly set out the contributions of this dissertation to the literature on switching costs and network externalities. Each subsequent chapter includes a detailed motivation and a review of related literature.

One should note, that network externalities have no dynamic consequences when switching costs are nil. In such a case, it is completely optimal for consumers to be myopic, as they can switch between brands as they please in every period. However, all existing dynamic models of network effects presume lock-in, that is sufficiently high switching costs, which prevent consumers from switching between brands. It is curious whether parallels drawn in the literature between the results of models with switching costs and those with network effects are due to genuine similarity between switching costs and network effects, or are just an artifact of presumption of lock-in in network effects models. In Chapter 2, written jointly with Toker Doganoglu, we conduct a theoretical analysis of competition between network technologies. We build on Klemperer (1987) and analyze competition in a two-period differentiated-products duopoly in the presence of both switching costs and network externalities. We show that they have opposite implications on the demand. While the former reduces demand elasticities, the latter increases them. Increases in marginal network benefits imply lower prices in both periods while the effects of switching costs are ambiguous. When network effects are strong, and switching costs are moderate, prices in both periods may be lower than those in a market without network effects and switching costs. Moreover, we show that the first period prices are quadratic-convex functions of the level of switching costs, therefore for certain parameter values increasing switching costs may reduce equilibrium prices. This point is very important, as the common message in the literature about fully dynamic models is that switching costs unambiguously increase steady state prices.

Usually, the theoretical results may be used only as logical arguments for the policy design. In many cases the theory provides ambiguous results, which depend on parameter values. For instance, in the model mentioned above, the levels of equilibrium prices depend on the magnitude of switching costs and network externalities. This emphasizes the importance of empirical studies in support for the theory. In the following chapters, I carry out three empirical analyzes of mobile telephony to identify and quantify the determinants of competition and consumers' choices.

In Chapter 3, also written jointly with Toker Doganoglu, we analyze the impact of network effects on the diffusion of mobile services in Germany using monthly data from January 1998 to June 2003. We use a random utility framework, discussed comprehensively in Anderson, de Palma and Thisse (1992) and Berry (1994), to estimate demands for mobile services provided by competing network operators. In the analyzed period, we observe the explosive growth in the subscriber base and the rather moderate decrease in prices. Our conjecture is that prices alone cannot account for such rapid diffusion. We explore the possible contribution of network effects to industry growth. In the estimation, we use publicly available market share data and price indices generated from data that we have collected. Our results suggest that network effects played a significant role in the diffusion of mobile services in Germany. In the absence of network effects, if prices remained as observed, the penetration of mobiles could be lower by at least 50%. Current penetration levels could be reached without network effects only if prices were drastically lower. Furthermore, assuming that observed prices are the result of pure strategy Nash equilibrium, we compute marginal costs and markups. The Lerner index for all network operators increased over time from about 13% in January 1998 to about 30% in June 2003. This increase is due to the fact that the margins remained almost constant while the prices decreased.

This analysis required collecting a unique database on pricing mobile services in Germany. We use monthly price listings published in telecommunications magazines and on the Internet, which include all tariffs of network operators and independent service providers in the time period January 1998 – June 2003. This database could be potentially used for further studies, such as an analysis of welfare effects from entry to mobile telephony or a study of the pricing strategies of mobile service providers.

Chapter 3 provides some information which may be helpful for policy design. The extremely high cost of licences in the UMTS auctions provoked a debate on the ability of firms to cover sunk costs and make further investments in consumer acquisition. As the widespread use of 3G technology is an important social objective, it is crucial to know to what extend the diffusion of 3G technology could be stimulated by network effects. Thus, the knowledge of price elasticities and network benefits in the 2G telephony could be some basis for projections onto 3G technology.

Chapter 4 presents an empirical analysis of switching costs in mobile telephony in the UK. The presence of switching costs may have negative consequences on social welfare because firms which have large market shares have incentives to charge higher prices and exploit locked-in consumers rather than compete for new ones. Therefore, it is important to provide measurements of switching costs. The empirical literature on switching costs is scarce. This is due to the lack of appropriate detailed data sets on individual choices. In this study, I use survey data on British households to estimate the magnitude of switching costs in mobile telecommunications industry. I employ the random utility framework, as developed by McFadden (1974). I estimate multinominal and mixed logit models to identify state dependence in the choices of network operators. According to mixed logit estimates for panel data there are significant negative switching costs which vary across network operators. The choices of network operators are also explained by observable and unobservable heterogeneity of tastes. The observable heterogeneity is represented by consumer characteristics such as: gender, age and employment status. When multinominal logit is estimated switching costs are overestimated due to ignorance of unobservable tastes. Thus, this study indicates the importance of unobservable heterogeneity of tastes in the estimation of switching costs. Both switching costs and persistent tastes of consumers lead to state-dependent choices of network operators. Furthermore, the estimation of logistic regression indicates that the probability of switching depends on consumer characteristics, such as age, usage intensity and ways of spending leisure time. These results are consistent with the findings in the consumer surveys conducted by the British regulator Oftel.

Chapters 3 and 4 identify and measure the magnitude of two key determinants of competition and consumers' choices in the mobile telephony. Apart from providing arguments for regulatory and competition policy, it is also important to assess the effectiveness of regulation which has been already implemented. In Chapter 5, I analyze the impact of regulation on the development and competitiveness of the mobile telecommunications industry across the European Union. In my view, the large differences in the level of technology adoption, prices and market structure across the EU countries are due to differences in regulatory policy and country specific characteristics. I refer to earlier studies measuring the impact of regulation on the diffusion of mobile services, such as Gruber and Verboven (2001). In a related paper, Parker and Röller (1997) estimate the determinants of market conduct in the mobile industry across the U.S. states. Using cross-country panel data, I estimate a reduced-form and a structural model, and find that prices are significantly influenced by the regulatory policy, which also explains the differences in demand for mobiles across the EU countries. In particular, the regulation implemented throughout the liberalization process of fixed telephone lines has a negative impact on prices for mobile services. Similarly, the implementation of number portability for mobile services has a negative impact on prices. Moreover, I estimate country specific average industry conducts, which allow me to compare the competitiveness of mobile telephony across the European Union. For the purpose of this study, I have created a comprehensive data set on the regulation in telecommunications industry in the European Union.

Chapter 2

Dynamic Duopoly Competition with Switching Costs and Network Externalities

2.1 Introduction

A product exhibits *network effects* when its value increases in the number of its users. On the other hand, switching costs arise when consumers face frictions to change the brand they consume either due to relationship specific investments or contractual obligations. In many industries switching costs and network effects co-exist. Take, for example, the case of computer software and operating systems such as Windows. The higher the number of Windows users, the more applications software will be provided for the Windows platforms which in turn will increase the value of the operating system inducing more people to adopt it—a typical example of indirect network effects. At the same time, software products require investments in learning to become familiar with their features software, which makes switching to a new set of software products costly. Similarly, mobile telecommunications is a textbook example for direct network effects as the higher number of subscribers imply more communication possibilities.

Switching costs in mobile telephony may arise due to transaction costs, such as the cost of changing and redistributing the phone number. Moreover, many mobile telephone operators subsidize handsets and require consumers to sign long term contracts, which may be costly to break.

Examples are plenty, and are presented in an illustrative manner elsewhere as in Shapiro and Varian (1998), Katz and Shapiro (1994), Klemperer (1995) and Farrell and Klemperer (2004). Interesting dynamic issues arising in industries with such characteristics have attracted economists' attention not only due to the intellectual challenges, but also due to increasing public policy debates over the operation of these industries. Thus, there is a large body of literature on network effects and switching costs which arose mainly in the last two decades. In fact, the recent survey by Farrell and Klemperer (2004) (FK hereafter) contains 35 pages of references suggesting a mature and saturated knowledge base.

We will follow FK in summarizing the main results of literature, and begin by noting that both network effects and switching costs could potentially extend the consumer choice problem dynamically. Current choices of consumers affect their future consumption leading to state dependent demands. Thus, expectations of consumers on future pricing policies and future size of sales of a firm play a key role in determining outcomes. In certain cases, historical accidents may determine long run behavior of a given industry. Firms face incentives inducing them to adopt "*bargains-then-ripoffs* type pricing policies. That is, early on firms compete fiercely to lock-in consumers, in order to exploit them in the future when switching costs are present, and in order to increase the willingness to pay of future generations in case of network effects. Locking into an inferior standard, excessive private incentives for incompatibility, distorted incentives for entry are common features of models studying such industries. In most models, consumers do not switch between brands in equilibrium. A message FK delivers is the similarity of outcomes in models with network effects and models with switching costs. For a full review of the literature, we refer the reader to FK and the references therein.

Surprisingly, however, there is no model which studies industries where both network effects and switching costs are present. Taking the risk of stating the obvious, we would like to note that network effects have *no* dynamic consequences when switching costs are nil. In such a case, it is completely optimal for consumers to be myopic, as they can switch between brands as they please every period. In a typical dynamic network effects model[1], consumers are assumed to purchase only once, usually as soon as they arrive to the market, and stay with their choice forever even though the net present value of buying an alternative might become positive at a future date.

To the best of our knowledge, all existing dynamic models of network effects presume lock-in, that is sufficiently high switching costs preventing consumers from switching between brands. Hence, it is curious whether parallels drawn between the results of models with switching costs and those with network effects are due to genuine similarity between switching costs and network effects, or just an artifact of presumption of lock-in in network effects models. Our goal in this paper is to attempt to identify the consequences of network effects and switching costs both on consumer behavior and strategies of firms when they co-exist in a meaningful way.

We adopt a very stylized model of preferences which allows consumers to switch between brands in equilibrium. We build on the model of Klemperer (1987) by simply appending a network benefit term to the valuation of products.[2] We will consider a simple two-period price setting model of competition between two firms which are horizontally differentiated à la Hotelling. Only some of the consumers survive to the next period. Those that leave the market are replaced by new consumers. Furthermore, some consumers receive a taste shock which changes their location on the unit interval, thus they might wish to switch the brand they buy. We assume that switching costs are sufficiently low that at least some of these consumers will be able to change the brand they purchase. The rest of the consumers are rigid, that is, their preferences

[1] See, for example, Farrell and Saloner (1986), Katz and Shapiro (1992).

[2] When network effects vanish, the model boils down to that of Klemperer (1987).

remain as in period one as well as they have very high costs hindering any desire to switch in the second period.[3]

Consumers form rational expectations of not only current network sizes but also of future network sizes and prices. Given prices consumers are able to compute fractions of current and future consumers buying from each firm correctly. For rational expectations demands to be well-behaved, that is to avoid situations where firms can corner the market, we assume that the marginal network benefits are sufficiently low.

We derive a subgame perfect equilibrium where firms share the market in both periods, in the second period some of the consumers with changing preferences switch the brands, while the rigid consumers purchase again from the same firm they shopped in the first period. This behavior could be supported in equilibrium only for certain parameters constellations. We derive sufficient conditions on the parameters, which simply states that switching costs must be sufficiently low to induce switching in the second period as well as the network effects in order to avoid tipping towards one product in each period, and the size of the population of rigid consumers must be sufficiently small.

The rational expectations demands we derive for each period exhibit interesting properties. First period demands become more price sensitive with higher marginal network benefits. In contrast, however, increasing switching costs reduce price sensitivity of first period demands. Thus, in the first period switching costs and network effects operate in completely opposite directions. In the second period, both switching costs and network effects imply a positive shift in demand for a firm which carries over a market share more than one half. However, the latter effect is present only when there are switching costs. That is, in the absence of switching costs, network effects have no dynamic consequences. The second period demands become more price sensitive when marginal network benefits increase, while switching costs have no impact on the price sensitivity.

[3]We keep the rigid segment in the model in order to preserve the parallels with Klemperer (1987). Alternatively, one could view our model as one with a distribution of switching costs in the population.

Second period equilibrium prices increase with the customer base of a firm carried over from the first period. However, the subgame perfect equilibrium outcome of the two period competition is symmetric. Thus, in both periods firms share the market equally. Second period prices increase in the share of rigid consumers, decrease with marginal network effects and are not affected by the switching costs.

First period prices are unambiguously reduced by higher marginal network benefits. However, switching costs may have different effects on the equilibrium prices. We explore how switching costs and network effects impact the equilibrium prices in the first period by means of Monotone Comparative Statics. This allows us to uncover the mechanisms that change equilibrium prices in response to a change in one of these features.

First period equilibrium prices turn out to be a quadratic-convex function of the switching costs faced by flexible consumers. Thus, for certain parameter constellations, increasing switching costs reduce first period prices. This occurs when marginal second period profits respond to a change in the switching costs more than first period marginal profits. We show that this could occur when switching costs are low, in particular, when there are no rigid consumers, there is no impact of a change in switching costs on marginal first period profits around zero, while second period marginal profits decrease in switching costs. Thus introducing slightly higher switching costs decrease first period prices.

Note that some of these results are obtained in the literature in models where switching costs and network effects are considered in isolation. Our results not only confirm existing ones, but also provide insights when these features exist together. For example, a policy conclusion we can draw is that whenever moderate switching costs exist together with relatively strong network effects, the market may be sufficiently competitive in terms of prices. Thus, a regulatory agency may refrain from costly intervention. Furthermore, we show that the U-shaped nature of first period equilibrium prices can be exploited in a way to improve consumer surplus. We show that a redistributable switching tax, even though it will always reduce aggregate welfare, may increase aggregate consumer surplus.

In section 2, we present the model. We derive the equilibrium and discuss its properties in section 3. Section 4 concludes.

2.2 The Model

As in Klemperer (1987), we analyze competition between two firms over two periods. The consumer population have peculiar characteristics. For example, they value the number of consumers purchasing a brand, they incur switching costs if they wish to change their brand choice, and some of them have changing tastes. The model is very stylized and builds on Klemperer (1987) by simply appending a network benefit component to the utilities of consumers. In fact, it is equivalent to that of Klemperer (1987) when network effects vanish. Let us begin by describing features of consumer utilities which remain the same over the two periods. We assume that consumers have a reservation price,[4] denoted by v, that is sufficiently high so that all consumers buy as soon as they arrive. The reservation price is the same for both products and all consumers in any period. Furthermore, each consumer has an affinity towards one of the brands in each period which could be due to effects of a typical consumer's social circle or exposure to different marketing mixes. We capture this affinity by means of a standard Hotelling horizontal differentiation model.

Thus, we assume firms a and b are located at opposite ends of the unit interval, that is $L_a = 0$ and $L_b = 1$ where L_i denotes the location of firm i. Consumers are assumed to be uniformly distributed between the two firms. If a consumer located at $x \in [0, 1]$ makes her purchase from i, she incurs a utility reduction equal to $t \mid x - L_i \mid$, where t measures the magnitude of this reduction, or with standard terminology unit "transport" costs. It is important to note that we do not interpret these costs literally

[4] We could also refer to this term as the stand alone value, as customary in the network effects literature.

as transportation costs. In our model, horizontal differentiation arise due to different reactions to marketing and hence a typical consumer may change her views over time.

Moreover, consumers derive a network benefit proportional to the number of other consumers purchasing a given product. That is, if a product is bought by N consumers, then each of these consumers derive a benefit equal to kN, where k measures the magnitude of network effects. In particular, we will require the magnitude of the network effects to be sufficiently small relative to the transportation costs in order to avoid situations where one firm corners the market. Hence, in each period, both firms will have positive sales.

The consumer population evolve in different ways from period one to two. Particularly, only a fraction, $1-\nu$, of the first period consumers survive to the next period, and those who leave the market are replaced by new unattached consumers. A second group of mass μ, receive a taste shock, and thus, are relocated along the unit interval. This taste shock could be interpreted as a change in a consumer's affinity due to changes in her social circle, as well as exposure to a different marketing mix. We assume the taste shock to be independent of first period tastes; admittedly a rather strong assumption.[5] Hence, some consumers may find a product different than what they have bought in the first period more attractive. However, to change the brand they consume, they will have to incur a switching cost, s, which we assume to be sufficiently small so that some consumers switch in equilibrium. The rest of the consumer population, with a mass of $1-\mu-\nu$, is rigid in their tastes and face much higher switching costs, s_r.[6] Therefore, they continue to purchase from the firm which they bought in the first period. For expositional ease, we refer to unattached second period consumers[7] as *new* (n), the group with changing preferences and low switching costs as *flexible* (f), and those with

[5] Similar modelling of changing preferences can be found in Klemperer (1987) and von Weiszäcker (1984).

[6] Notice that even if they have changing preferences, sufficiently high switching costs would prevent them from switching.

[7] One could include this group to those with changing preferences, but assume that this group incurs zero switching costs. Thus, if we allow everybody to change their preferences, we arrive at a model with a distribution of switching costs; namely, none, moderate, and high.

high switching costs and constant tastes as *rigid* (r) consumers.

In summary, the net first period utility of a consumer located at $x \in [0,1]$ can be written as

$$U_1^i(x, p_1^i, N_1^i) = v + kN_1^i - \mid x - L_i \mid t - p_1^i, \qquad i = \{a, b\}$$

where N_τ^i and p_τ^i represent the expected network size and the retail price of firm i at period τ. While the second period utility, which also is a function of their type and first period choice, is given by

$$U_{2h}^{i|j}(x, p_2^i, N_2^i) = \begin{cases} v + kN_2^i - \mid x - L_i \mid t - p_2^i & \text{if } i = j \text{ or } j = 0, \text{ and } h \in \{n, f, r\}, \\ v + kN_2^i - \mid x - L_i \mid t - p_2^i - s & \text{if } i \neq j, \ j \neq 0 \text{ and } h = f, \\ v + kN_2^i - \mid x - L_i \mid t - p_2^i - s_r & \text{if } i \neq j, \ j \neq 0 \text{ and } h = r, \end{cases}$$

Consumers choose that brand which maximizes their utility. This problem is relatively easier in the second period, since consumers will learn their types, and given this information and their expectations on the contemporary network sizes, they will select the brand which provides them with the highest net benefit. On the other hand, the first period choice is significantly more involved. First, consumers are uncertain about which group they will belong to in the second period. Moreover, since their choice this period constrains their behavior due to potential switching costs, they need to have beliefs about future. Given prices in the first period, they need to form expectations about current and future network sizes and future prices. We will adopt Rational Expectations (RE) as the mechanism for expectation formation. A typical consumer will select the brand that maximizes the expected discounted sum of lifetime utilities,

$$U^j(x, p_1^j, N_1^j) = U_1^j(x, p_1^j, N_1^j) + \delta E\big[U_{2h}^{i|j}(\chi, p_2^i, N_2^i) \mid j, p_1^a, p_1^b\big],$$

where δ is the discount factor and $E[\cdot \mid \cdot]$ is the conditional expectations operator. Expectations are taken over the distribution of types, and distribution of potential second period tastes. Notice that the cumulative expected utilities depend only on the first period observables. Consumers compute N_1^j,N_2^j and p_2^j rationally. That is, N_τ^j is a demand function conditional on prices in τ, and delivers the realized network sizes for all relevant prices for $\tau = 1, 2$. In the first period, consumers solve the firms' problem in the future and anticipate second period equilibrium prices and therefore network sizes exactly.

Firms select prices in order to maximize their discounted cumulative profits. For simplicity we assume that firms have the same discount factor as consumers, δ. We assume away fixed costs, and normalize marginal costs zero which is quite an innocent assumption given the linearity of consumer utilities. We presume that firms cannot distinguish among old locked-in and new consumers, and thus, restrict firms strategies to nondiscriminatory, linear prices.[8]

2.3 The Two-Period Game

Given the preferences we have introduced, we will look for a subgame perfect equilibrium in prices. However, we have certain ex ante restrictions on the nature of this equilibrium. We presume that the market is covered and shared in each period which in turn requires conditions on v and k. Furthermore, we assume some of the flexible consumers are able to switch in equilibrium in both directions which imposes an upper bound on s. On the other hand, the switching costs faced by the rigid types need to be sufficiently high so that they continue buying the same brand in the second period. Furthermore, these main features should occur for each level of market share firms carry over from the first period. In the following, we first derive the equilibrium strategies assuming that the conditions which make such outcomes possible are met, and

[8]We would like to note that price discrimination is potentially a powerful instrument to extract more surplus from the locked-in consumers while competing aggressively for the new ones. If we have allowed firms to practice price discrimination among their locked in consumers and first time buyers, they would prefer loosing their low valuation locked in customers—the ones who end up closer to the other firm in the second period—to their competitors. The intuition of this is similar to poaching behavior studied in Fudenberg and Tirole (2000) as well as Gehrig and Stenbacka(2004). We stick with linear pricing and no price discrimination in this paper to be comparable to the previous literature; mainly to Klemperer (1987).

then derive restrictions on the parameters such that this outcome can be supported in equilibrium.

2.3.1 The Second Period

We start solving the two-period game by finding the second period equilibrium prices. We first need to derive second period demand functions in order to construct the profits. Due to switching costs, the second period choices of consumers which remain in the market depend on their first period choices, therefore we need to find the demands from each consumer group. Let us first consider the new unattached consumers who are distributed uniformly along the unit interval with mass ν. This group simply compares the utilities from product a and b, and select the brand which provides them the highest net benefit. Thus, finding the indifferent consumer is sufficient to identify the demand faced by firms from this group of consumers. Formally, let $d_2^{a|0}$ denote this location, then it must satisfy $U_{2n}^{a|0}(d_2^{a|0}, p_2^a, N_2^a) = U_{2n}^{b|0}(1 - d_2^{a|0}, p_2^b, 1 - N_2^a)$ where p_2^i and N_2^i are the second period price and expected network size of firm i respectively. Notice due to the fact that consumers are uniformly distributed, $d_2^{a|0}$ also is equal to the fraction of new consumers buying from firm a. Solving this equation yields,

$$d_2^{a|0} = \frac{1}{2} + \frac{k}{2t}[2N_2^a - 1] + \frac{1}{2t}[p_2^b - p_2^a], \tag{2.1}$$

and since we assume that the market is covered $d_2^{b|0} = 1 - d_2^{a|0}$.

The group of flexible consumers, which has a mass of μ, evaluate each product anew as they are now placed at a different point along the unit interval. For example, one consumer who was closest to firm a in period one, could very well be closer to firm b in period 2. Therefore, who they have bought from in the first period has a crucial impact on their second period choice. Let us first consider those who have bought from a in the first period. Identifying the demands of this group of consumers is once again equivalent to finding the indifferent consumer with one difference. Even though firm 2 announces a retail price of p_2^b, consumers face $p_2^b + s$ when they consider buying from b. Recall our prevailing assumption that switching costs, s, are sufficiently low that some will prefer switching to firm b. Let us denote the fraction of consumers from this group which prefer firm a by $d_2^{a|a}$. Then, it must satisfy $U_{2f}^{a|a}(d_2^{a|a}, p_2^a, N_2^a) = U_{2f}^{b|a}(1-d_2^{a|a}, p_2^b, 1-N_2^a)$, and is given by

$$d_2^{a|a} = \frac{1}{2} + \frac{k}{2t}[2N_2^a - 1] + \frac{1}{2t}[p_2^b + s - p_2^a]. \tag{2.2}$$

The fraction of consumers who has bought a in the first period, but prefers b in the second period is simply $d_2^{b|a} = 1 - d_2^{a|a}$. Applying similar arguments, the fraction of flexible consumers who have purchased from b and switches to a, $d_2^{a|b}$, solves $U_{2f}^{a|b}(d_2^{b|a}, p_2^a, N_2^a) = U_{2f}^{b|b}(1 - d_2^{a|b}, p_2^b, 1 - N_2^a)$, and is given by

$$d_2^{a|b} = \frac{1}{2} + \frac{k}{2t}[2N_2^a - 1] + \frac{1}{2t}[p_2^b - p_2^a - s]. \tag{2.3}$$

Likewise, the fraction of consumers who remain loyal to b is $d_2^{b|b} = 1 - d_2^{a|b}$. Notice that these consumers perceive firm a's price as $p_2^a + s$.

Finally, the fraction of consumers with unchanged preferences $(1-\nu-\mu)$ will choose in the second period exactly the same brand as before, since their switching cost s_r is assumed to be sufficiently high.

Therefore, the total second period demand faced by firm $i \in \{a, b\}$ in period 2 is given by

$$d_2^i = \mu[d_2^{i|a}N_1^a + d_2^{i|b}N_1^b] + (1 - \mu - \nu)N_1^i + \nu d_2^{i|0}, \qquad i = \{a, b\}. \tag{2.4}$$

Rational expectations about the network sizes imply $N_2^a = d_2^a$ and $N_2^b = 1 - N_2^a = 1 - d_2^a = d_2^b$. Let

$$\alpha = \frac{s\mu + t(1 - \mu - \nu)}{2(t - k\mu - k\nu)}$$

and

$$\beta = \frac{\mu + \nu}{2(t - k\mu - k\nu)}.$$

Solving (2.4) with imposing the rational expectations restrictions yields

$$d_2^a = \frac{1}{2} + \beta(p_2^b - p_2^a) + \alpha[2N_1^a - 1], \tag{2.5}$$

and $d_2^b = 1 - d_2^a$. For each firm to face downward sloping demand curves, $t - k\mu - k\nu > 0$ must hold; that is, the network benefits must be relatively small compared to the transportation costs or the share of rigid consumers must be relatively high.

It is easy to verify that whenever $t - k\mu - k\nu > 0$

$$\frac{\partial \alpha}{\partial s} = \frac{\mu}{2(t - k\mu - k\nu)} > 0,$$

$$\frac{\partial \beta}{\partial s} = 0,$$

$$\frac{\partial \alpha}{\partial k} = \frac{(s\mu + t(1 - \mu - \nu))(\mu + \nu)}{2(t - k\mu - k\nu)^2} = 2\alpha\beta > 0,$$

and

$$\frac{\partial \beta}{\partial k} = \frac{(\mu + \nu)^2}{2(t - k\mu - k\nu)^2} = 2\beta^2 > 0.$$

Thus, a close inspection of (2.5) suggests that, the second period demand of a firm with a user base larger than one half shifts outward, while the demand of the other firm contracts when switching costs increase. However, the price responsiveness of the demand is not affected by the same change which is an artifact of our two period model. Since there is no future, neither the new consumers nor the flexible ones need to worry about low current prices implying high ones in the future and vice versa.

Similarly, a slight increase in k not only shifts the demand of the firm with a higher user base outward, but also makes the demands more sensitive to price differentials. The price effect is due to rational expectations; i.e., consumers observing a price differential expect the demand of the lower price firm to increase both due to an increase in utility via price directly and via the network benefits indirectly. The upward shift in demand however occurs only when coupled with switching costs. When $s = 0$ and

$\nu + \mu = 1$, that is when there are no switching costs and no rigid consumers, the network effects only have an impact via price sensitivities.

It is exactly this point which has not received much attention in the literature. The similarities between results obtained in models with switching costs and in models with network effects arise due to the outward shift of the demand when consumers are locked-in. But what locks consumers in is not the network effects, it is the switching costs which are usually assumed to be very high that no one switches.

Given that the fixed and marginal costs are normalized to zero, the second period profit functions of the firms are simply their revenues and given by $\Pi_2^a = p_2^a d_2^a$ and $\Pi_2^b = p_2^b d_2^b$. And due to the linearity of demands, the profit functions are concave in the own price of each firm.[9] Thus, first order conditions(FOCs) describe a candidate Nash equilibrium with prices given by

$$\begin{aligned} p_2^i &= \frac{1}{2\beta} + \frac{\alpha}{3\beta}[2N_1^i - 1] \qquad (2.6) \\ &= \frac{t}{\nu + \mu} - k + \frac{1}{3}\frac{(s\,\mu + t(1-\nu-\mu))\left(2\,{N_1}^i - 1\right)}{\nu+\mu}, \qquad i = \{a, b\}. \end{aligned}$$

However, note that we have imposed certain behavioral assumptions on the demand side when we derived rational expectations demands. These behavioral assumptions translate to constraints which firms should take into account when formulating their best responses. Namely, we require some consumers to switch brands in the second period which is only possible when $0 < {d_2}^{a|b} \leq {d_2}^{a|a} < 1$. If this condition holds, then $0 < {d_2}^{a|0} < 1$, since ${d_2}^{a|b} \leq {d_2}^{a|0} \leq {d_2}^{a|a}$. Observe that both ${d_2}^{a|a}$ and ${d_2}^{a|b}$ will be functions of N_1^i in equilibrium, therefore these restrictions should hold for every possible value of N_1^i, namely $0 \leq N_1^i \leq 1$. This is necessary, since, in the first period, firms would foresee the equilibrium in the second period. By restricting our attention to cases where the postulated behavior occurs for each N_1^i, we avoid situations where second period profit functions become non-differentiable for certain strategies that might arise in the first

[9] Notice that $\beta \geq 0$.

period.

Furthermore, as $\mu + \nu \to 0$, firms place a higher weight on revenues from the rigid consumers, and since these consumers face very high switching costs, each firm will find it most profitable to exploit this segment to the fullest extent. Namely, they might select their prices in order to drive the net surplus of the marginal rigid consumer to zero, which in turn might drive their demand from new and flexible consumers to zero. In fact, such a strategy may be profitable for any value of $\mu+\nu$ when v is large enough. Remember also that we have assumed v to be sufficiently large that all consumers buy for reasonable ranges of prices. Even though we do not explicitly derive the necessary conditions, we assume that v is sufficiently large to induce all consumers to participate, while it is sufficiently small that neither firm finds it optimal to just serve the rigid consumers for all $0 \leq N_1^i \leq 1$ and all reasonable prices of the other firm.

Let

$$\mathcal{P} = \left\{\mu + \nu \in \left[\frac{2}{5}, 1\right], k \in \left[0, k_{max}\right], s \in \left[0, s_{max}\right]\right\}$$

where

$$s_{max} = t - \frac{t(1-\nu)(1-k\beta)}{t\beta + (2\mu+\nu)(1-k\beta)},$$

and

$$k_{max} = \frac{2}{3}t.$$

At the candidate equilibrium prices, the type of behavior we have postulated, i.e. new consumers buy from both firms, some flexible consumers switch to the other brand, and rigid ones stick to their first period choice, is realized if parameters belong to $\mathcal{P}$.

Lemma 1 *A sufficient condition for the second period prices given in (2.6) to constitute a Nash equilibrium is $(\mu + \nu, k, s) \in \mathcal{P}$. At these prices, the equilibrium demands are*

$$d_2^i = \frac{1}{2} + \frac{1}{3}\alpha(2N_1^i - 1) \tag{2.7}$$

and the equilibrium profits are

$$\Pi_2^i(N_1^i) = \frac{1}{36\beta}[3 + 2\alpha(2N_1^i - 1)]^2 \tag{2.8}$$

where $i = \{a, b\}$.

Proof. See Appendix.[10]

The second period equilibrium prices have a few interesting properties. First observe that, whenever $k < k_{max}$, $t - k\mu - k\nu > 0$, thus β is positive and demands are downward sloping. Moreover, since α is also positive, the demand function of a firm carrying over a market share that is larger than one half from the first period shifts outward enabling this firm to charge a higher price. Furthermore, the second period profits are increasing in the first period customer base which makes lock-in valuable. This would give both firms incentives to compete more fiercely in the first period.

Both second period equilibrium prices and profits increase in switching costs when a firm has a customer base, N_1^i, that is larger than one half. Thus, a firm which dominates in terms of market shares in the first period would benefit from an increase in the switching costs. On the other hand, an increase in the network effects, k, decrease both the price and profit of a firm which carries over more than half of the first period consumers to the second period. Hence, switching costs and network effects are forces which act in completely opposite directions in equilibrium in the second period.

If the firms carry over a market share that is closed to one half from the first period and $\mu + \nu \to 1$, then the second period equilibrium prices could well fall below t, the price which would have prevailed in the absence of switching costs and network effects. Consequently, the presence of network effects might make the second period fiercely competitive as well.

[10] We would like to emphasize once again that the restrictions defining $\mathcal{P}$ are only sufficient but not necessary to induce the postulated behavior. Thus, the equilibrium prices are valid for a larger set of parameters.

2.3.2 The First Period

Consumers face a much more complicated task in decision making in the first period. They need to evaluate a stream of benefits for two periods for each product in order to select one. Consumers do not know their type initially, thus they need to figure out their second period actions conditional on first period choices as well as the realizations of their type. With probability ν, they will leave the market in which case they receive no benefits, while with probability $1-\mu-\nu$, they will be rigid and will buy the same brand as in the first period. They will belong to the group of flexible consumers, i.e. will be redistributed along the unit interval, with probability μ. Therefore, they will switch to the other brand with some probability whichever brand they buy in the first period. For example, if they are considering the second period benefit conditional on having bought brand a in the first period, they will know that they will switch to brand b if their new location along the unit interval is larger than $d_2^{a|a}$ and remain with brand a otherwise. Formally, their expected benefit will be

$$EU^a = \int_0^{d_2^{a|a}} U_{2f}^{a|a}(\chi, p_2^a, N_2^a)d\chi + \int_{d^{a|a}}^1 U_{2f}^{b|a}(\chi, p_2^b, N_2^b)d\chi.$$

Similarly, the expected benefit of a flexible consumer conditional on buying brand b in the first period can be written as

$$EU^b = \int_0^{d_2^{a|b}} U_{2f}^{a|b}(\chi, p_2^a, N_2^a)d\chi + \int_{d^{a|b}}^1 U_{2f}^{b|b}(\chi, p_2^b, N_2^b)d\chi.$$

In doing these complicated calculations, we assume that consumers rationally infer next period prices (p_2^a, p_2^b), next period network sizes (N_2^a, N_2^b) and critical values determining whether they switch or not, $(d_2^{a|a}, d_2^{a|b})$. Observe that each of these quantities in equilibrium turns out to be a function of first period customer base of each brand, and thus, first period prices. Therefore, given first period prices, rational consumers should be able to compute first period demands which in turn determine second period equilibrium prices, network sizes, and critical values.

Hence, in the first period, a rational consumer chooses that brand which delivers highest lifetime utility, that is they compare

$$U^a(x, p_1^a, N_1^a) = [v - p_1^a - tx + kN_1^a] + \delta\Big[\mu EU^a + (1-\mu-\nu)\big[v - p_2^a - tx + kN_2^a\big]\Big]$$

and

$$\begin{aligned} U^b(x, p_1^b, N_1^b) &= [r - p_1^b - t(1-x) + kN_1^b] \\ &\quad + \delta\Big[\mu EU^b + (1-\mu-\nu)\big[r - p_2^b - t(1-x) + kN_2^b\big]\Big]. \end{aligned}$$

Computing the difference yields

$$\begin{aligned} U^a(x, p_1^a, N_1^a) - U^b(x, p_1^b, N_1^b) &= p_1^b - p_1^a + (t - k + 2kN_1^a - 2tx) \\ &\quad + \frac{\delta s\mu}{t}\big(k(2N_2^a - 1) + p_2^b - p_2^a\big) \\ &\quad + \delta(1-\mu-\nu)\big(p_2^b - p_2^a + (t - k + 2kN_2^a - 2tx)\big), \end{aligned} \tag{2.9}$$

where we have used $N_1^b = 1 - N_1^a$ and $N_2^b = 1 - N_2^a$. Observe that the right hand side of (2.9) is decreasing in x, the distance from brand a. Thus, if there is a consumer indifferent between the brands, all those consumers to the left will purchase brand a and to the right will buy brand b.

The demands faced by firms, once again, can be identified by finding the location of the indifferent consumer in the first period. Let d_1^a denote this location then it solves

$$U^a(d_1^a, p_1^a, N_1^a) - U^b(d_1^a, p_1^b, N_1^b) = 0. \tag{2.10}$$

Rational expectations on first period network sizes require $d_1^a = N_1^a = 1 - N_1^b = 1 - d_1^b$. Imposing this condition as well as substituting second period prices from (2.6), second period rational expectations network sizes from (2.7), we solve (2.10) for the first period demands yielding

$$d_1^i = \frac{1}{2} + \frac{p_1^j - p_1^i}{\gamma}, \qquad i \in \{a, b\} \quad \text{and} \quad j \neq i, \tag{2.11}$$

where

$$\gamma = 2(t-k) + 2t\delta(1-\mu-\nu) + \frac{4}{3}\frac{\alpha\delta(s\mu + t(1-\mu+\nu))(1-k\beta)}{t\beta}.$$

Whenever $k \leq k_{max}$, we have $t - k > 0$ and $1 - k\beta > 0$, implying $\gamma > 0$, therefore first period demands are downward sloping.[11]

Switching costs and network effects have their impact on the first period demands through γ. A brief inspection reveals that

$$\frac{\partial\gamma}{\partial k} = -2 - \frac{8\delta\alpha^2}{3} < 0,$$

and

$$\frac{\partial\gamma}{\partial s} = \frac{8\delta\mu\alpha(1-k\beta)}{3t\beta} > 0.$$

That is, the first period demand becomes more sensitive to prices with an increase in network effects, while they become less price sensitive with an increase in switching costs. The latter is due to the fact that, rational consumers forecast a larger price for the firm which carries over a larger customer base to the second period—the lower priced firm in the first period. Hence, consumers do not easily buy in to initial price cuts. On the other hand, a lower price in the first period implies a larger group of consumers who would be "locked-in" in the second period implying a larger network benefit. A lower price in the first period allows consumers to coordinate on one firm not only in the first period but also in the second period. The difference between switching costs and network effects are starker in the first period; they are demand side forces in completely opposite directions.

[11] We would like to note that when $k = 0$, γ reduces to y introduced in Klemperer (1987) pp. 148.

The cumulative profit functions of the firms are $\Pi^a = p_1^a d_1^a + \delta\Pi_2^a(d_1^a)$ and $\Pi^b = p_1^b d_1^b + \delta\Pi_2^b(d_1^b)$, where Π_2^a and Π_2^b are the second period equilibrium profits given in (2.8). These profit functions are concave in own prices whenever $4\delta\alpha^2 < 9\gamma\beta$. We show in the appendix that when we restrict our attention to parameters in $\mathcal{P}$, this condition indeed is satisfied. Hence solving the FOCs yields symmetric first period candidate equilibrium prices given by

$$p_1^a = p_1^b = \frac{1}{2}\gamma - \frac{2\delta\alpha}{3\beta}. \tag{2.12}$$

At these prices the profits of the firms are equal and given by

$$\Pi^i = \frac{\gamma}{4} + \frac{\delta}{4\beta} - \frac{\delta\alpha}{3\beta}, \qquad i = \{a, b\}, \tag{2.13}$$

which we show, in the appendix, to be non-negative when $(\mu + \nu, k, s) \in \mathcal{P}$.

Proposition 1 *A sufficient condition for the prices given in (2.12) to constitute a Nash equilibrium in the first period is $\{\mu + \nu, k, s)\} \in \mathcal{P}$. The equilibrium first period demands turn out to be*

$$d_1^a = d_1^b = \frac{1}{2}. \tag{2.14}$$

Given the first period customer bases, the second period equilibrium prices are also symmetric and given by

$$p_2^a = p_2^b = \frac{t}{\mu + \nu} - k \tag{2.15}$$

while the equilibrium demands in the second period also turn out be

$$d_2^a = d_2^b = \frac{1}{2}. \tag{2.16}$$

Proof. See appendix.

The second period equilibrium prices[12] are always positive, while the first period

[12]Note once again that we only provide sufficient conditions in proposition 1, and the equilibrium is valid for a larger set of parameters.

prices could be negative. [13] The first period equilibrium prices are quadratic convex in s—a feature we explore further when $\mu + \nu \to 1$ below. It is important to note that the quadratic convex nature of equilibrium prices implies that for some parameter constellations, increasing the switching cost slightly may lead to a decrease in first period prices. This is particularly interesting since we have previously shown that increasing the switching costs reduces demand elasticities in the first period. However, it also increases the value of carrying over a larger user base to the second period. We analyze the relative importance of these effects in subsection 2.3.3.

Klemperer (1987) recognizes that first period prices may be lower than those in a market without switching costs. However, he does not acknowledge the U-shaped nature of of first period prices in switching costs which may have further policy implications. We present one such implication in subsection 2.3.5.

On the other hand, both first and second period prices decrease in the marginal network benefits, k.[14] Therefore, when there are network effects, anticompetitive concerns in markets with switching costs may be reduced. In fact, the higher the network effects the lower the prices, and there may be cases where prices fall below those in a market without rigid consumers, network effects and switching costs. That is, any worry policy makers might have concerning high prices due to switching costs may not be well founded in the presence of sufficiently strong network effects.

Let p_τ^{sk} be the equilibrium prices in the presence of both switching costs and network effects, p_τ^k be the equilibrium price when only network effects exist, p_τ^s be the equilibrium price with just switching costs and p_τ be the equilibrium price without switching costs and network effects in period τ. It is easy to verify that $p_2 = t/(\mu+\nu)$ and $p_1 = t(1 + \delta(1 - \mu - \nu)/3)$. Observe that as $\mu + \nu \to 1$, both p_1 and p_2 approach t, the price that would have prevailed in a static standard Hotelling model. In the following proposition, we summarize relationships of these prices both in the first and

[13] One likely configuration where first period prices can be negative occurs when $s \to s_{max}$, $k \to k_{max}$, $\delta \to 1$, $\mu + \nu \to 1$ and $\mu > 1/2$.

[14] First period prices are decreasing in k, since γ is decreasing in k, while α/β is constant in k.

second period.

Proposition 2 (Price Orders)

1. *The second period equilibrium prices can be ordered in two ways:*

    - *Low network benefits:* $p_2^s > p_2^{sk} > p_2 > p_2^k$
    - *High network benefits:* $p_2^s \geq p_2 > p_2^{sk} > p_2^k$,

2. *The first period equilibrium prices must fulfill two conditions:*

    - $p_1^s > p_1^{sk}$ *and* $p_1 > p_1^k$

Notice the indeterminacy of first period price rankings. As we have noted above, first period prices could fall below marginal cost—zero, in our model—for certain parameter constellations. In the next subsection, we investigate the incentives of firms in setting their prices in the first period, and try to uncover the mechanisms through which switching costs and network effects shape the first period equilibrium. The clear message, however, is that the presence of network effects reduce prices in both periods.

2.3.3 The Monotone Comparative Statics

In this subsection, we explore further the impact of switching costs and network effects on first period prices. We employ monotone comparative statics (MCS) to uncover the mechanisms both these features affect the incentives of the firms.[15] The MCS allow us to separate the impact of switching costs and network benefits on the equilibrium prices into first and second period effects. In the arguments below we maintain the assumption that the parameters are in the set where the equilibrium we have derived in Proposition 1 exists.

[15]In doing so we follow Vives (1999), pp.34-39.

The derivative of the best response function of firm a, $R(p_1^b, s, k)$ with respect to switching costs can be written as[16]

$$\frac{\partial}{\partial s}R(p_1^b,s,k) = -\frac{\frac{\partial^2}{\partial s \partial p_1^a}\Pi^a(R(p_1^b,s,k),p_1^b,s,k)}{\frac{\partial^2}{\partial {p_1^a}^2}\Pi^a(R(p_1^b,s,k),p_1^b,s,k)}.$$

The denominator is negative because the profits are concave in p_1^a. Thus, the sign of the left hand side depends on the sign of the numerator, which is determined by a few non-zero partial derivatives and given by[17]

$$\frac{\partial^2\Pi^a}{\partial s\partial p_1^a} = p_1^a\frac{\partial^2 d_1^a}{\partial s\partial p_1^a} + \delta p_2^a\left[\left(\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a} + \frac{\partial d_2^a}{\partial d_1^a}\right)\frac{\partial^2 d_1^a}{\partial s\partial p_1^a} + \left(\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial^2 p_2^b}{\partial s\partial d_1^a} + \frac{\partial^2 d_2^a}{\partial s\partial d_1^a}\right)\frac{\partial d_1^a}{\partial p_1^a}\right] \quad (2.17)$$

When we evaluate (2.17) at the first period equilibrium prices, we obtain the direction of change in the best response function of firm a in the first period due to a change in s around the equilibrium. After substituting the expressions for partial derivatives and equilibrium prices, we get

$$\begin{aligned}\frac{\partial^2\Pi^a}{\partial s\partial p_1^a} \quad = \quad & \underbrace{\frac{3\gamma\beta - 4\alpha\delta}{6\beta}\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{+/-} \\ & +\delta\frac{1}{2\beta}\Bigg[\underbrace{\beta\left(-\frac{2\alpha}{3\beta}\right)\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{-} + \underbrace{2\alpha\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{+} \\ & + \underbrace{\beta\left(-\frac{2\mu}{3(\mu+\nu)}\right)\left(-\frac{1}{\gamma}\right)}_{+} + \underbrace{\frac{\mu}{t-\mu k-\nu k}\left(-\frac{1}{\gamma}\right)}_{-}\Bigg],\end{aligned} \quad (2.18)$$

which after simplifications yields

$$\frac{\partial^2\Pi^a}{\partial p_1^a\partial s} \quad = \quad \frac{2\delta\,\mu}{3\gamma t\beta}\left(2\,\alpha\,(1-k\,\beta) - \frac{t\,\beta}{\nu+\mu}\right). \quad (2.19)$$

[16]We will only present the results here; see appendix for their derivation. Similar arguments apply for the best response function of firm b due to symmetry.

[17]In writing (2.17), we suppressed arguments of $d_1^a = d_1^a(p_1^a, p_1^b, s, k)$, $p_2^b = p_2^b(d_1^a(p_1^a, p_1^b, s, k), s, k)$, and $d_2^a = d_2^a(p_2^a(d_1^a(p_1^a, p_1^b, s, k), s, k), p_2^b(d_1^a(p_1^a, p_1^b, s, k), s, k), d_1^a(p_1^a, p_1^b, s, k), s, k)$.

All derivatives in (2.17) have definite signs except the first period effect, which depends on the sign of first period prices. Switching costs affect second period marginal profits through several different channels, however overall effect is ambiguous.[18] When first period prices are positive, marginal first period profits are increasing in the switching costs. This is due to the increase in γ, which in turn reduces first period demand elasticity. The reduction in the first period demand elasticity also impact second period incentives, first, through a negative indirect effect of the second period price of firm b, p_2^b, on firm a's second period demand, d_2^a (2nd term in (2.17)); and second, through a positive direct effect of the first period demand, d_1^a, on the second period demand (3rd term in (2.17)). The overall contribution of these three effects on the incentives of firm a is positive yielding incentives to increase first period price, irrespective of the sign of the first period equilibrium prices.

The fourth term in (2.17) results from the decrease in the responsiveness of second period price of firm b, p_2^b, to the first period demand, d_1^a, due to an increase in switching costs. When the first period price, p_1^a, increases, the first period demand, d_1^a, falls, which encourages firm b to raise its second period price, p_2^b, and therefore the second period demand, d_2^a, and profits increase. When switching costs grow in magnitude, the increase in firm b's price is more, leading to incentives for firm a to increase first period prices. The fifth term is due to a positive change in the responsiveness of the second period demand, d_2^a, to the first period demand when switching costs increase. An increase in the first period price p_1^a decreases the first period demand d_1^a, which decreases the second period demand d_2^a and the profits. When switching costs rise, the second period demand decreases more implying a negative impact on profits which leads to an incentive to decrease first period prices. It is straightforward to show that these two effects combined have a negative sign.

The overall direction of the movement of the best response function of firm a is ambiguous. However, notice that the term in parenthesis in (2.19) is linearly increasing

[18]All the arguments below are based on the sign of partial derivatives given in (2.18), however they are followed best referring to equation (2.17).

in s.[19] Thus, if the right hand side of (2.17) is positive at $s = 0$, it is positive for all s. Otherwise, best response function of firm a shifts downwards around the equilibrium for small s, implying lower equilibrium prices with a slightly higher s.

A similar analysis can be performed for network benefits. The change in the marginal profits due to a change in marginal network benefits, k, is induced through three non-zero partial derivatives

$$\frac{\partial^2 \Pi^a}{\partial k \partial p_1^a} = p_1^a \frac{\partial^2 d_1^a}{\partial k \partial p_1^a} + \delta p_2^a \left[\frac{\partial d_2^a}{\partial p_2^b} \frac{\partial p_2^b}{\partial d_1^a} + \frac{\partial d_2^a}{\partial d_1^a} \right] \frac{\partial^2 d_1^a}{\partial k \partial p_1^a}, \tag{2.20}$$

after the substituting the expressions for partial derivatives and equilibrium prices we obtain

$$\begin{aligned} \frac{\partial^2 \Pi^a}{\partial k \partial p_1^a} &= \underbrace{\frac{3\gamma\beta - 4\alpha\delta}{6\beta} \left(- \frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{+/-} \\ &\quad + \delta \frac{1}{2\beta} \left[\underbrace{\beta \left(- \frac{2\alpha}{3\beta} \right) \left(- \frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{+} + \underbrace{2\alpha \left(- \frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{-} \right] \qquad (2.21) \\ &= -\frac{3 + 4\delta\alpha^2}{3\gamma} < 0. \qquad (2.22) \end{aligned}$$

Apart from the first period term, once again the effects of an increase in network benefits have well determined signs. The overall effect is unambiguously negative, implying that best response function of firm a shifts down around the equilibrium. Since firm b's reaction function moves also downward, equilibrium is obtained at lower prices when network effects increase.

In contrast to the switching costs, higher network benefits result in a more elastic demand in the first period for positive prices. And, the impact of increasing network effects on the cumulative profits only operate through this increase in first period demand elasticity as can be seen in (2.20). The second period effects go through two

[19] This is due to the fact that α is linearly increasing in s.

channels, first a negative indirect effect of firm b's second period price, p_2^b, on firm a's second period demand, d_2^a, and second, through a direct positive impact of the first period demand of firm a on the second period demand.

In summmary, the MCS we present in (2.18) and (2.21) not only allow us to disentangle the first and second period effects of changes in switching costs and network effects on pricing incentives of the firms in the first period, but also to identify the channels which these changes affect incentives.

2.3.4 The Case without Rigid Consumers

A few of the results we have presented in the previous subsection become sharper when we consider the case without rigid consumers, i.e., $\mu + \nu \to 1$. This simply assumes that every consumer, which survives from period one to two, could potentially switch, and firms as well as consumers are all aware of this possibility. A brief inspection of (2.12), suggest that second period prices decrease, however, the effects in the first period prices is not immediately seen as decreasing the size of the rigid consumers negatively impact second period profits and could reduce the first period incentives to lock customers in. Nevertheless, if we keep μ constant and let $\rho = \mu + \nu$, i.e., replace rigid consumers with new unattached ones, it is possible to show that

$$\frac{\partial p_1^a}{\partial \rho} = -\frac{1}{3} \frac{\left(2\, s\, \mu\, (t - k\, \rho)^2 (s\, \mu + t) + (s\, \mu\, k - t\, (t - k))^2 \rho^2\right) \delta}{\rho^2 t\, (t - k\, \rho)^2} < 0,$$

thus also first period prices decrease.

Next, we investigate the effect of changes in switching costs faced by flexible consumers and network effects when $\mu + \nu \to 1$. Substituting $\mu = 1 - \nu$ in (2.17), after simplifications, yields

$$\frac{\partial^2 \Pi^a}{\partial s \partial p_1^a} = \frac{\delta(1-\nu)[s(1-\nu)(2t-3k) - t(t-k)]}{\delta(1-\nu)^2 s^2 (2t-3k) + 3t(t-k)^2} \tag{2.23}$$

The denominator is always positive when $k < k_{max}$. Hence, the sign of this expression depends on the numerator, which is positive for $s > \frac{t(t-k)}{(1-\nu)(2t-3k)}$ and negative otherwise. More importantly, when $s = 0$, a slight increase in switching costs shift both best response functions downwards leading to lower first period equilibrium prices. Thus, when switching costs are sufficiently low, the incentives to exploit locked-in consumers in the second period dominates and first period competition is fiercer.

In particular, consider the case when switching costs are zero, which implies first period equilibrium prices of $p_1^i = t - k$. After substitution of $\mu = 1 - \nu$ and $s = 0$ in (2.18), one can show that

$$\left.\frac{\partial^2 \Pi^a}{\partial s \partial p_1^a}\right|_{s=0,\mu=1-\nu} = 0 + \delta(t-k)\left[0 + 0 + \frac{1-\nu}{6(t-k)^2} - \frac{1-\nu}{2(t-k)^2}\right] = -\frac{\delta(1-\nu)}{3(t-k)}.$$

Clearly the decrease in equilibrium prices is due to the impact of a small increase in switching costs on future profits, since the first period effect is identically zero. A similar result can be found in Doganoglu (2005) where it is shown in a fully dynamic setup that small switching costs might lead to lower prices in steady state compared to no switching costs.

2.3.5 Switching Taxes: A Policy Suggestion

In this subsection, we present a rather interesting policy implication of our results. The fact that by making switching costly between firms, first period equilibrium prices may be reduced suggests that there is a possibility of increasing first period consumer benefits. A feature of our model which limits this increase is the fact that market size is constant. That is, we assume that all the consumers buy anyways, therefore the reduction in prices do not lead to an increase in the size of the consuming population. The effects of switching costs on market participation remains an interesting issue to explore, however it is beyond the scope of the current paper. Still, we are able to argue below that even though introduction of a switching tax reduces aggregate welfare, consumer surplus can be increased in detriment to firms' profits.

After lengthy but straightforward computations, aggregate welfare, that is the equally weighted sum of the consumer surplus and profits, turns out to be

$$W = (1+\delta)(r - \frac{t}{4}) + (1+\delta)\frac{k}{2} - \delta s\mu(\frac{1}{2} - \frac{s}{2t}) - \frac{\delta\mu s^2}{4t}. \tag{2.24}$$

The first term represents the welfare in a market without switching costs and network effects over two periods. The second term accounts for the aggregate network benefits, as every consumer has access to a network of size one half in both periods. The third term corresponds to the losses which arise in the second period when some flexible consumers decide to incur the switching costs and change the firm they buy from. The fourth term, on the other hand, is due to the inefficient allocation of flexible consumers to the firms in the second period. Notice that some flexible consumers located to the right of the midpoint between the firms continue to buy from firm 1 in the second period instead of patronizing firm 2 which is closer to their location. This introduces a welfare loss as the cost of extra distance travelled by these consumers.

If a policy maker were to institute a switching tax, some of the losses in the second period could be avoided by refunding the tax revenue to consumers. That is, the third term in (2.24) will vanish if s were to be interpreted as a redistributable tax. This interpretation is more sensible when there are no rigid consumers, i.e. when $\mu + \nu \to 1$—a case we focus on below. Nevertheless, such a tax would still reduce aggregate welfare due to inefficient allocation of consumers among the firms in the second period, since the fourth term in (2.24) will not vanish. However, incurring this cost may yield a significant shift of surplus from the firms to the consumers via the decrease in the first period prices. Whenever $\mu + \nu \to 1$, the first period prices can be simplified to

$$p_1^* = t - k - \frac{2}{3t}\delta\mu s(t - \mu s) - \frac{\delta\mu^2 s^2 k}{t(t-k)}. \tag{2.25}$$

Notice that the last two terms are negative whenever the equilibrium we describe in proposition 1 exists, hence, introducing a switching tax, s, will reduce prices in the first period.

Consider an industry without switching costs and no rigid consumers. Introducing a redistributable switching tax, s, will increase consumer surplus in the first period by an amount equal to the last two terms of (2.25), while reducing it in the second period by an amount equal to the fourth term of (2.24), hence the net change in consumer surplus is given by

$$\Delta CS = \frac{2}{3t}\delta\mu s(t-\mu s) + \frac{\delta\mu^2 s^2 k}{t(t-k)} - \frac{\delta\mu s^2}{4t},$$

which is easily shown to be quadratic concave function of s, with $\partial\Delta CS/\partial s\big|_{s=0} > 0$. Therefore, the change in consumer surplus is positive for positive switching tax levels. As we mentioned above, such a policy may increase consumer surplus, nonetheless reduce profits even more that the aggregate welfare will go down. A policy maker whose objective is biased towards consumer benefits, i.e. one which places a much lower weight to profits, would find such a policy attractive however. Doganoglu (2005) presents a similar case in favor of switching taxes in a fully dynamic model based on welfare comparisons in the steady state.

2.4 Conclusion

We have analyzed the two-period model of duopolistic competition with switching costs and network effects, built on the model of Klemperer (1987). We have shown that switching costs and network effects are forces in opposite directions early on. That is, consumer would like to be part of a network which would be large in the future. But firms with large user bases are able to sustain high prices in the presence of switching costs, thus reducing their attractiveness for consumers early on. The clear signs of these phenomena can be exemplified in our first period demands, which becomes more(less) price sensitive with an increase in marginal network benefits (switching costs). When there are no switching costs, the size of a network does not play an important dynamic role, as can be seen in the second period demands we have derived. Network effects increase price sensitivity of consumers when expectations are rationally formed, since in this case a price decrease not only has a direct positive impact on the utility of a marginal customer, but also an indirect effect through the network benefits.

Subgame perfect(SP) equilibrium prices in both tend to be lower as network effects increase. In both periods, this is due to increased price elasticity of demands faced by firms. The effects of switching costs, on the other hand, on the equilibrium outcomes are less clear cut. In the second period, the switching costs faced by flexible consumers tend to increase the price charged by a firm which carries over an installed base larger than one half. However, in the SP equilibrium of the whole game, switching costs have no effect. Nevertheless, the second period on the SP equilibrium prices increase with an increase in the size of the population of rigid consumers.

The effects of switching costs on the first period equilibrium prices is ambiguous. Even though the firms face demands with a lower price elasticity when switching costs increase, they also face a more profitable second period when they are able lock in more than half of the first period consumers. While the former effect leads to incentives to increase prices, the latter encourages firms to reduce their prices. Hence, the equilibrium is attained when these opposing incentives are balanced.

However, there is no telling ex-ante where this balancing would occur. Thus our first period prices could be lower than those in a market without network effects and switching costs. We show that the first period prices are quadratic-convex functions of the level of switching costs, therefore for certain parameter values increasing switching costs may reduce equilibrium prices. We can see this clearly in our example without rigid consumers, where around zero, increasing switching costs have no impact on marginal first period profits while it reduces second period profits, leading to lower equilibrium prices.

This point is very important to note, as the common message in the literature studying fully dynamic models is that switching costs unambiguously increase steady state prices. A common assumption shared by all the fully dynamic models is that switching costs are sufficiently high that consumers do not expect to switch, and in equilibrium there is no switching. However, it is not obvious whether this would be the case for small switching costs as our model in this paper suggests. Essentially, one would expect that in a fully dynamic model, firms would be in a situation much like the first period, but at the same time have some installed bases. Thus in a steady state, we expect the prices to inherit the same U-shape as we have derived in this paper. In a related model, Doganoglu (2005) shows that in fact for small switching costs steady state prices may be below those in a market without switching costs. We have shown that this property may be exploited to increase aggregate consumer surplus by introducing a switching tax.

Naturally, there are a few directions in which one could extend this paper. We think that a fully dynamic analysis is warranted. A more interesting issue is related to the market size. In this model, the total demand is completely inelastic, that is all consumers buy no matter what. However, both network effects and switching costs are likely to have effects on the participation incentives of the marginal consumer. A thorough welfare analysis could only be conducted, when these incentives are taken into account.

2.5 Appendix

Proof of Lemma 1

We have imposed certain behavioral assumption on the demand side when we derived rational expectations demands in the second period. Namely, market is covered, both firms make positive sales to all the consumer types, and some flexible customers of each firm find it better to switch to the other brand. Switching in both directions occur, for each $N_1^a \in [0,1]$, only when

$$0 < d_2^{a|b} \leq d_2^{a|a} < 1,$$

which in turn implies $0 < d_2^{a|0} < 1$, since $d_2^{a|b} \leq d_2^{a|0} \leq d_2^{a|a}$.

When we evaluate $d_2^{a|a}$ given in (2.2), at the second period rational expectations demands and equilibrium prices, we obtain

$$1 - d_2^{a|a} = \frac{2}{3}\,\frac{\alpha\,(1-k\,\beta)\,N_1^a}{t\,\beta} + \frac{1}{2}\,\frac{t-s}{t} - \frac{1}{3}\,\frac{\alpha\,(1-k\,\beta)}{t\,\beta}. \tag{2.26}$$

Similarly, when we evaluate $d_2^{a|b}$ given in (2.3),

$$d_2^{a|b} = -\frac{2}{3}\,\frac{\alpha\,(1-k\,\beta)\,N_1^a}{t\,\beta} + \frac{1}{2}\,\frac{t-s}{t} + \frac{1}{3}\,\frac{\alpha\,(1-k\,\beta)}{t\,\beta} \tag{2.27}$$

For switching to occur in between both brands, we need the right hand sides of both (2.26) and (2.27) to be positive for all $N_1^a \in [0,1]$. Observe that $1-d_2^{a|a}$ increases in N_1^a when $k \leq k_{max}$, therefore we need to evaluate the right hand side of (2.26) at $N_1^a = 0$. On the other hand, $d_2^{a|b}$ decreases in N_1^a requiring us to evaluate the right hand side of (2.27) at $N_1^a = 1$. It is easy to verify that both (2.26) and (2.27), evaluated at $N_1^a = 0$ and $N_1^a = 1$ respectively lead to the same condition, namely,

$$\frac{1}{2}\,\frac{t-s}{t} - \frac{1}{3}\,\frac{\alpha\,(1-k\,\beta)}{t\,\beta} > 0,$$

which yields, after substituting for α and simplifying, an upper bound on s given by

$$s \leq t - \frac{t(1-\nu)(1-k\beta)}{t\beta + (2\mu+\nu)(1-k\beta)} \equiv s_{max}.$$

It is easy to see that $s_{max} \leq t$, whenever $1-k\beta > 0$ which holds when $k \leq 2t/3 \equiv k_{max}$. However, in order to guarantee that there are some positive switching costs, we need $s_{max} > 0$. Observe that

$$\frac{\partial}{\partial k} s_{max} = \frac{3}{4} \frac{t(1-\nu)(\mu+\nu)^2}{(t\beta + (2\mu+\nu)(1-k\beta))^2 (t - k\mu - k\nu)^2} > 0,$$

therefore the smallest value of s_{max} occurs when $k = 0$, and given by

$$s_{max}\Big|_{k=0} = \frac{t}{5\mu + 3\nu}\big[5(\mu+\nu) - 2\big],$$

and is positive whenever $\mu + \nu > 2/5$. Therefore whenever $(\mu + \nu, s, k) \in \mathcal{P}$, some first period consumers of firm a switch to firm b, while some customer of b switch to a and the new customers buy from both firms in equilibrium for all $N_1^a \in [0, 1]$. By assumption, we have that v, the reservation price of consumers, is sufficiently large that all consumer buy, while it is sufficiently small that neither firm prefers to serve just the rigid consumers. Therefore, prices given in (2.6) constitute a Nash equilibrium in the second period.

■

Proof of Proposition 1

We solve the FOCs of each firm simultaneously implied by the cumulative profit functions to obtain the candidate first period equilibrium prices given in (2.12). To show that these prices indeed constitute a Nash equilibrium in the first period, we need to prove then when $(\mu + \nu, k, s) \in \mathcal{P}$, γ is nonnegative, cumulative profit functions are concave in the price of each firm's own price, and equilibrium profits are nonnegative.

Concavity of profit functions:

Concavity of profit function requires

$$0 < \frac{4}{9}\frac{\delta\alpha^2}{\beta} < \gamma,$$

therefore, whenever profit functions are concave $\gamma > 0$. Rewriting the above condition, we require

$$H = \gamma - \frac{4}{9}\frac{\delta\alpha^2}{\beta} > 0,$$

which yields

$$H = 2\,t - 2\,k + 2\,\delta\,t\,(1 - \nu - \mu) + \frac{2}{9}\,\frac{(s\,\mu + t - t\,\nu - t\,\mu)^2\,\delta\,(-9\,k\,\nu + 5\,t - 9\,k\,\mu)}{t\,(\nu + \mu)\,(t - k\,\mu - k\,\nu)},$$

when we substitute the expressions for α and β. It is straightforward to verify that

$$\frac{\partial H}{\partial k} = -2 - \frac{8}{9}\,\frac{(s\,\mu + t - t\,\nu - t\,\mu)^2\,\delta}{(t - k\,\mu - k\,\nu)^2} < 0.$$

Thus, it is sufficient to show that $H > 0$ when $k = k_{max}$. Evaluating, H at $k = k_{max}$ yields

$$\begin{aligned} H \;=\; & \frac{2}{3}\,t + 2\,\delta\,t\,(1 - \nu - \mu) - \frac{2}{3}\,\frac{\delta\,(s\,\mu + t\,(1 - \nu - \mu))^2}{t\,(3 - 2\,\mu - 2\,\nu)} \\ & + 4\,\frac{\delta\,(s\,\mu + t\,(1 - \nu - \mu))^2\,(1 - \nu - \mu)}{t\,(\nu + \mu)\,(3 - 2\,\mu - 2\,\nu)} \end{aligned} \tag{2.28}$$

Notice that only the third term is negative. Furthermore, $s\mu + t(1 - \mu - \nu) < t$, thus the third term becomes even more negative when we replace $s\mu + t(1 - \mu - \nu)$ with t. Hence, it is easy to verify that

$$\begin{aligned} H \;&\geq\; \frac{2}{3}\,t - \frac{2}{3}\,\frac{\delta\,t}{(3 - 2\,\mu - 2\,\nu)} \\ &=\; \frac{2t}{3}\Big[1 - \frac{\delta}{3 - 2(\mu + \nu)}\Big] \geq 0, \end{aligned}$$

since $\delta \leq 1$ and $3 - 2(\mu + \nu) \geq 1$. Therefore, the profit function are concave in firm's own prices. Moreover, $\gamma > 0$. □

Equilibrium profits are non-negative:

The equilibrium profit from both periods is given (2.13) and this expression is once again decreasing in k. Thus, it is sufficient to verify that profits are non-negative when $k = k_{max}$. Substituting the expressions for γ, α, β and $k = k_{max}$ in (2.13) yields

$$\begin{aligned} G &= \frac{t}{6} + \frac{1}{2}\delta\, t\,(1-\nu-\mu) + \frac{\delta\,(s\,\mu + t\,(1-\nu-\mu))^2\,(1-\nu-\mu)}{t\,(\nu+\mu)\,(3-2\,\mu-2\,\nu)} \\ & \quad -\frac{1}{3}\,\frac{\delta\,(s\,\mu + t\,(1-\nu-\mu))}{\nu+\mu} + \frac{1}{6}\frac{\delta t(3-2\mu-2\nu)}{\mu+\nu}. \end{aligned}$$

Notice that only the fourth term is negative. It is easy to verify that

$$\begin{aligned} G &\geq \frac{t}{6} - \frac{1}{3}\,\frac{\delta s\mu}{\nu+\mu} + \frac{1}{6}\frac{\delta t}{\mu+\nu} \\ &\geq \frac{t}{6}\big[1 - \frac{\delta\mu}{\mu+\nu}\big] + \frac{t}{6}\,\frac{\delta(1-\mu)}{\mu+\nu} \geq 0, \end{aligned}$$

where the first inequality follows from simply ignoring second and third terms in G, second inequality from $s \leq t$ and the last from the fact that $\delta < 1$, $s \leq t$, $\mu \leq 1$ and $\mu/(\mu+\nu) \leq 1$. Therefore, in equilibrium firms obtain nonnegative profits, even if they charge below cost prices in the first period. □

Each firm's profit function is concave in its own price, and equilibrium profits are nonnegative when $(\mu + \nu, k, s) \in \mathcal{P}$, hence solution of FOCs indeed describe an equilibrium.

■

Monotone comparative statics

A convenient method to disentangle effects of certain variables on firms incentives is to use Monotone Comparative Statics (MCS). Essentially, MCS tells us how the best response function of a firm will shift if one of the model parameters changes.

Consider two-period profit of firm a for a fixed p_1^a and p_1^b:

$$\Pi^a(p_1^a, p_1^b, s, k) \quad = \quad p_1^a d_1^a(p_1^a, p_1^b, s, k) + \delta \Pi_2^a(d_1^a(p_1^a, p_1^b, s, k), s, k),$$

where

$$\Pi_2^a(d_1^a(p_1^a, p_1^b, s, k), s, k) \quad = \quad p_2^a(d_1^a(p_1^a, p_1^b, s, k), s, k) d_2^a,$$

and

$$d_2^a = d_2^a(p_2^a(d_1^a(p_1^a, p_1^b, s, k), s, k), p_2^b(d_1^a(p_1^a, p_1^b, s, k), s, k), d_1^a(p_1^a, p_1^b, s, k), s, k).$$

We will suppress the dependency of d_1^a, p_2^a, p_2^b and d_2^a on their arguments below for ease of exposition.

Let $R(p_1^b, s, k)$ denote the best response price of firm a when firm b charges p_1^b. Then, the FOC implies

$$\frac{\partial}{\partial p_1^a} \Pi^a(R(p_1^b, s, k), p_1^b, s, k) = 0,$$

and therefore

$$\frac{\partial}{\partial s} R(p_1^b, s, k) = -\frac{\frac{\partial^2}{\partial s \partial p_1^a} \Pi^a(R(p_1^b, s, k), p_1^b, s, k)}{\frac{\partial^2}{\partial {p_1^a}^2} \Pi^a(R(p_1^b, s, k), p_1^b, s, k)}.$$

A similar expression also applies for changes in marginal network benefits, k. Given that profit function of firm a is concave in p_1^a, it is easy to see that

$$\operatorname{sign}\left[\frac{\partial}{\partial s} R(p_1^b, s, k)\right] = \operatorname{sign}\left[\frac{\partial^2}{\partial s \partial p_1^a} \Pi^a(R(p_1^b, s, k), p_1^b, s, k)\right].$$

We can, therefore, find out how the best response of a firm will change with respect to a change in switching costs, and more importantly identify through which channels this change takes place, by looking at the derivative of the first order condition with respect to the switching costs holding first period prices at p_1^b and firm a's best response to it as constant. A particularly appealing choice is setting p_1^b to the first period equilibrium price of firm b, in which case firm a's best response is simply also to charge the equilibrium price. Thus, MCS around the equilibrium prices will allow us characterize the equilibrium incentives of firms in a transparent manner.

The FOC of firm a in the first period is

$$\frac{\partial^2 \Pi^a}{\partial p_1^a} = d_1^a + p_1^a \frac{\partial d_1^a}{\partial p_1^a} + \delta \left[\left(d_2^a + p_2^a \frac{\partial d_2^a}{\partial p_2^a} \right) \frac{\partial p_2^a}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} + p_2^a \frac{\partial d_2^a}{\partial p_2^b} \frac{\partial p_2^b}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} + p_2^a \frac{\partial d_2^a}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} \right].$$

Observe that

$$d_2^a + p_2^a \frac{\partial d_2^a}{\partial p_2^a} = 0,$$

since it is the FOC in the second period, and it is identically zero because in a subgame perfect equilibrium firm's take equilibrium payoffs from future given at their equilibrium level. Therefore, the derivative of the FOC with respect to switching costs, holding first period prices constant, amounts to

$$\begin{aligned}
\frac{\partial^2 \Pi^a}{\partial s \partial p_1^a} = \; & \frac{\partial d_1^a}{\partial s} + p_1^a \frac{\partial^2 d_1^a}{\partial s \partial p_1^a} \\
& + \delta \left[\left(\frac{\partial p_2^a}{\partial d_1^a} \frac{\partial d_1^a}{\partial s} + \frac{\partial p_2^a}{\partial s} \right) \frac{\partial d_2^a}{\partial p_2^b} \frac{\partial p_2^b}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} \right. \\
& + p_2^a \left(\frac{\partial^2 d_2^a}{\partial s \partial p_2^b} \frac{\partial p_2^b}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial p_2^b} \frac{\partial^2 p_2^b}{\partial s \partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial p_2^b} \frac{\partial p_2^b}{\partial d_1^a} \frac{\partial^2 d_1^a}{\partial s \partial p_1^a} \right) \\
& + \left(\frac{\partial p_2^a}{\partial d_1^a} \frac{\partial d_1^a}{\partial s} + \frac{\partial p_2^a}{\partial s} \right) \frac{\partial d_2^a}{\partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} \\
& \left. + p_2^a \left(\frac{\partial^2 d_2^a}{\partial s \partial d_1^a} \frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial d_1^a} \frac{\partial^2 d_1^a}{\partial s \partial p_1^a} \right) \right].
\end{aligned}$$

Let us first list a few partial derivatives which will also be useful in our analysis with respect to network effects. It is straightforward to confirm that

$$\begin{aligned}
\frac{\partial d_1^a}{\partial p_1^a} &= -\frac{1}{\gamma}, & \frac{\partial d_2^a}{\partial d_1^a} &= 2\alpha, \\
\frac{\partial d_2^a}{\partial p_2^b} &= \beta, & \frac{\partial p_2^b}{\partial d_1^a} &= -\frac{2\alpha}{3\beta}, & \frac{\partial p_2^a}{\partial d_1^a} &= \frac{2\alpha}{3\beta}.
\end{aligned}$$

The partial derivatives of involving d_1^a with respect to switching costs are

$$\frac{\partial d_1^a}{\partial s} = -(p_1^a - p_1^b)\frac{1}{\gamma^2}\frac{\partial \gamma}{\partial s} = 0, \qquad \frac{\partial^2 d_1^a}{\partial s \partial p_1^a} = \frac{1}{\gamma^2}\frac{\partial \gamma}{\partial s} = \frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta},$$

and those involving d_2^a are

$$\frac{\partial^2 d_2^a}{\partial s \partial d_1^a} = \frac{\mu}{t - \mu k - \nu k}, \qquad \frac{\partial^2 d_2^a}{\partial s \partial p_2^b} = 0.$$

We have only one term involving p_2^a given by

$$\frac{\partial p_2^a}{\partial s} = \frac{2(p_1^b - p_1^a)}{3\gamma\beta}\frac{\partial \alpha}{\partial s} = 0,$$

and another involving p_2^b which is given by

$$\frac{\partial^2 p_2^b}{\partial s \partial d_1^a} = -\frac{2\mu}{3(\mu+\nu)}.$$

After eliminating the elements equal to zero we arrive at

$$\frac{\partial^2 \Pi^a}{\partial s \partial p_1^a} = p_1^a \frac{\partial^2 d_1^a}{\partial p_1^a \partial s} + \delta p_2^a \left[\left(\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a} + \frac{\partial d_2^a}{\partial d_1^a} \right) \frac{\partial^2 d_1^a}{\partial s \partial p_1^a} + \left(\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial^2 p_2^b}{\partial s \partial d_1^a} + \frac{\partial^2 d_2^a}{\partial s \partial d_1^a} \right) \frac{\partial d_1^a}{\partial p_1^a} \right]$$

and after substituting the partial derivatives and equilibrium price we obtain

$$
\begin{aligned}
\frac{\partial^2 \Pi^a}{\partial s \partial p_1^a} &= \underbrace{\frac{3\gamma\beta - 4\alpha\delta}{6\beta}\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{+/-} \\
&+\delta\frac{1}{2\beta}\Bigg[\underbrace{\beta\Big(-\frac{2\alpha}{3\beta}\Big)\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{-} + \underbrace{2\alpha\frac{8\delta\mu\alpha(1-k\beta)}{3t\gamma^2\beta}}_{+} \\
&\underbrace{\beta\Big(-\frac{2\mu}{3(\mu+\nu)}\Big)\Big(-\frac{1}{\gamma}\Big)}_{+} + \underbrace{\frac{\mu}{t-\mu k-\nu k}\Big(-\frac{1}{\gamma}\Big)}_{-}\Bigg]
\end{aligned}
$$

A similar analysis might be conducted for network benefits. The derivative of the first order condition with respect to marginal network benefits, k, yields

$$
\begin{aligned}
\frac{\partial^2 \Pi^a}{\partial k \partial p_1^a} &= \frac{\partial d_1^a}{\partial k} + p_1^a\frac{\partial^2 d_1^a}{\partial k \partial p_1^a} \\
&+\delta\Bigg[\Big(\frac{\partial p_2^a}{\partial d_1^a}\frac{\partial d_1^a}{\partial k} + \frac{\partial p_2^a}{\partial k}\Big)\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} \\
&+p_2^a\Big(\frac{\partial^2 d_2^a}{\partial k \partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial p_2^b}\frac{\partial^2 p_2^b}{\partial k \partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial^2 d_1^a}{\partial k \partial p_1^a}\Big) \\
&+ \quad \Big(\frac{\partial p_2^a}{\partial d_1^a}\frac{d_1^a}{\partial k} + \frac{\partial p_2^a}{\partial k}\Big)\frac{\partial d_2^a}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} \\
&+p_2^a\Big(\frac{\partial^2 d_2^a}{\partial k \partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial d_1^a}\frac{\partial^2 d_1^a}{\partial k \partial p_1^a}\Big)\Bigg].
\end{aligned}
$$

The partial derivatives with respect to marginal network benefits involving d_1^a are

$$
\frac{\partial d_1^a}{\partial k} = -(p_1^a - p_1^b)\frac{1}{\gamma^2}\frac{\partial \gamma}{\partial k} = 0, \qquad \frac{\partial^2 d_1^a}{\partial k \partial p_1^a} = \frac{1}{\gamma^2}\frac{\partial \gamma}{\partial k} = -\frac{6+8\delta\alpha^2}{3\gamma^2},
$$

those involving d_2^a are

$$
\frac{\partial^2 d_2^a}{\partial k \partial d_1^a} = 4\alpha\beta, \qquad \frac{\partial^2 d_2^a}{\partial k \partial p_2^b} = 2\beta^2.
$$

Once again, we have only one term involving p_2^a given by

$$\frac{\partial p_2^a}{\partial k} = \frac{2d_1^a - 1}{3\beta}\frac{\partial \alpha}{\partial k} - \frac{3 + 2\alpha(2d_1^a - 1)}{6\beta^2}\frac{\partial \beta}{\partial k} + \frac{2\alpha}{3\beta}\frac{\partial d_1^a}{\partial k} = -1,$$

and another involving p_2^b which is given by

$$\frac{\partial^2 p_2^b}{\partial k \partial d_1^a} = 0.$$

Thus, after eliminating elements equal to zero results in

$$\begin{aligned}
\frac{\partial^2 \Pi^a}{\partial k \partial p_1^a} &= p_1^a \frac{\partial^2 d_1^a}{\partial k \partial p_1^a} \\
&+\delta p_2^a \Bigg[\frac{1}{p_2^a}\frac{\partial p_2^a}{\partial k}\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial^2 d_2^a}{\partial k \partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a}\frac{\partial^2 d_1^a}{\partial k \partial p_1^a} \\
&+ \quad \frac{1}{p_2^a}\frac{\partial p_2^a}{\partial k}\frac{\partial d_2^a}{\partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial^2 d_2^a}{\partial k \partial d_1^a}\frac{\partial d_1^a}{\partial p_1^a} + \frac{\partial d_2^a}{\partial d_1^a}\frac{\partial^2 d_1^a}{\partial \partial p_1^a}\Bigg].
\end{aligned} \tag{2.29}$$

Notice that

$$-\frac{1}{p_2^a}\frac{\partial p_2^a}{\partial k}\frac{\partial d_2^a}{\partial p_2^b} = \frac{\partial^2 d_2^a}{\partial k \partial p_2^b} = 2\beta^2,$$

as well as

$$-\frac{1}{p_2^a}\frac{\partial p_2^a}{\partial k}\frac{\partial d_2^a}{\partial d_1^a} = \frac{\partial^2 d_2^a}{\partial k \partial d_1^a} = 4\alpha\beta,$$

thus, second and third, fifth and sixth terms cancel each other in (2.29), leaving only

$$\frac{\partial^2 \Pi^a}{\partial k \partial p_1^a} = p_1^a \frac{\partial^2 d_1^a}{\partial k \partial p_1^a} + \delta p_2^a \left[\frac{\partial d_2^a}{\partial p_2^b}\frac{\partial p_2^b}{\partial d_1^a} + \frac{\partial d_2^a}{\partial d_1^a} \right] \frac{\partial^2 d_1^a}{\partial k \partial p_1^a}.$$

After substituting the partial derivatives and equilibrium prices we obtain

$$\begin{aligned}
\frac{\partial^2 \Pi^a}{\partial p_1^a \partial k} &= \underbrace{\frac{3\gamma\beta - 4\alpha\delta}{6\beta}\left(-\frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{+/-} \\
&+\delta \frac{1}{2\beta}\Bigg[\underbrace{\beta\left(-\frac{2\alpha}{3\beta} \right)\left(-\frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{+} + \underbrace{2\alpha\left(-\frac{6 + 8\delta\alpha^2}{3\gamma^2} \right)}_{-} \Bigg]
\end{aligned} \tag{2.30}$$

Chapter 3

Estimating Network Effects in Mobile Telephony in Germany

Introduction

In the last decade mobile telephony has been the fastest growing segment in the telecommunications industry. In June 2003, after a few years of exponential growth, there were more than 60 million subscribers of mobile telephony providers in Germany. Between January 1998 and June 2003, the total number of subscribers grew by about 700%. During the same period of time, the index of prices for mobile services calculated by the German Statistical Office came down by about 41%. Whether such a moderate price decrease can fuel the exponential change in the market size is a question that awaits an answer.

At a first glance, it is unlikely that prices alone can account for such a large increase in the user base. The introduction of prepaid cards and new services, such as the short message service (SMS) and wireless application protocol (WAP), together with increasing attractiveness of handsets has played a very important role for the industry development. However, network effects may be another force which can rationalize such tremendous growth rates. A product that exhibits network effects becomes more valuable when more people use it. In our opinion, network effects influence consumers' subscription decisions to mobile services.

Network effects in mobile telephony may have different origins. First, an increase in the number of mobile users raises communications possibilities. In particular, the consumption of mobile services can be attributed to a single person and not to a household. This implies a much larger potential market size than in the case of fixed telephony. Second, in addition to voice telephony, mobile firms can offer several other services, such as SMS, MMS, WAP and email, which may themselves be subject to network effects. Finally, the spread of mobile services within an individual's social circle may exert social pressure inducing her to subscribe. For instance, lack of mobile contact may lead to exclusion from spontaneous social events.

In this paper, we investigate whether network effects have an impact on the subscription decisions of consumers to mobile telephony services in Germany. Our analysis is based on publicly available industry data, namely subscription levels, prices and churn rates in the period from January 1998 to June 2003 in monthly intervals. One of our main goals is to present a simple methodology which employs such limited information, and yet can enhance our understanding of the evolution of the mobile industry.

The most easily accessible industry statistics in Germany, as in many other countries worldwide, are the subscription levels—that is, the total number of subscribers. Although interesting in describing the state of the industry, this information by itself is hardly useful in studying how consumer demand responds to changes in industry determinants. An important shortcoming is due to the fact that often consumers sign long term deals with their service providers, and hence, do not engage in decision making every month. A simple first difference of the subscription levels, unfortunately, does not correspond to sales, because a significant amount of consumers with expiring contracts resign with their previous operator. Thus, using installed bases as a proxy of sales would underestimate the role of network effects, since most consumers, particularly those which are locked in, would not be able to respond to changes in network sizes.

In this paper, we propose using churn rates to impute the fraction of switching consumers and approximate the number of locked in consumers—i.e., those who do not make subscription decisions.[1] A simple first difference of the observed subscription levels and the number of locked in consumers, then, should yield a good approximation for the number of new contracts sold. The second set of important variables we need are firm specific prices. However, these are hard to find in a prepared form since the German Statistical Office provides only aggregate price indices. Nevertheless, industry magazines and various Internet sites provide detailed information on the tariffs offered by each provider. These can be used to construct operator-specific price indices.

We use these variables, i.e. installed bases, sales and prices along with several other control variables, in estimating a system of demand equations. A clear drawback of working with limited data is naturally the constraint it imposes upon the sophistication of the estimated model. Therefore, we employ rather standard methods and standard functional forms which have been successfully employed in earlier literature on network effects. We explicitly state the economic and statistical assumptions necessary for interpreting results of our simple estimation methodology based on rather limited data as indicative of the strength of network effects in mobile telephony.

We use a standard aggregate nested logit model á la Berry (1994). We assume that consumers first decide whether to subscribe to fixed telephony services only or to mobile and fixed services, together. By normalizing with respect to the utility of fixed telephony services, one can impute the mean utility levels of subscribing to mobile telephony services via a simple transformation of observed market shares. We then posit a relatively straightforward linear utility for subscribing to mobile services, and search for parameters that allow our linear model to best explain the observed mean utility levels.

[1]We do not have precise information about the number of people with expiring contracts and with nil switching costs. We assume that all consumers with zero switching costs change network operators.

In modeling network effects, we use the lagged total share of subscribers in the population to proxy for network size. This assumes perfect compatibility between services of the providers and the lack of price mediated network effects due to different on-net and off-net prices. We test the appropriateness of this specification in two ways. In the first extension, we allow own network size to have a different effect than the size of the other operators' network. We cannot reject the hypothesis that the network effects are **not** firm specific—which supports our formulation. The second extension we explore tests whether the linear specification we use is appropriate. We re-estimated the model using a Box-Cox transformation of the network size. We cannot reject the hypothesis that the network sizes affect utility in a linear fashion.

Our results suggest that network effects played a significant role in the diffusion of mobile services in Germany. In the absence of network effects, if prices remained as observed, the penetration of mobiles could be lower by at least 50%. Current penetration levels could be reached without network effects only if prices were drastically lower. Moreover, assuming that observed prices result from pure strategy Nash equilibrium, we compute marginal costs and margins.[2] The Lerner index for all network operators increased over time from about 13% in January 1998 to about 30% in June 2003. This increase is due to the fact that the margins remained almost constant while the prices decreased.

The next section provides a short overview of empirical literature on network effects and the telecommunications industry. In section 2 we present a brief history and the state of the mobile industry in Germany. The model which we use for econometric analysis is presented in section 3. Data description and estimation results follow in sections 4 and 5, respectively. Finally, we conclude our analysis in section 6.

[2]Clearly, the assumption of a static Nash equilibrium is highly likely to be incorrect given the dynamic evolution of demand. Nevertheless, this exercise provides a crude first order approximation to markups and their evolution, and hence, is informative.

3.1 Literature

There is a growing body of literature that tries to measure indirect and direct network effects in a variety of network industries. For instance, Gandal, Kende and Rob (2000) study the diffusion of CD technology and find that the number of CD titles available has an impact on the consumer's willingness to adopt to the CD player. Park (2003) analyzes the role of network effects in the standard war between VHS and Betamax video recording systems. Similarly, Ohashi (2001) estimates a random utility model and measures the role of network externalities in the diffusion of VCR in the U.S. between 1978 and 1986. Clements and Ohashi (2004) estimate indirect network effects in the U.S. video game market between 1994 and 2002 using a nested logit model. Goolsbee and Klenow (2000) estimate a reduced form diffusion model for home computers and find that people are more likely to adopt computer technology in areas with a higher fraction of computer users.

There are a number of earlier papers that focus on estimating a hedonic price function for products that exhibit network effects. Brynjolfsson and Kemerer (1996) use the hedonic pricing model to determine the impact of network effects, defined as compatibility with the dominant standard, on the prices of microcomputer spreadsheets. Similar approaches are employed by Hartmann and Teece (1990), Gandal (1994), Economides and Himmelberg (1995), Moch (1995) and Gröhn (1999). For an excellent review of the theoretical and empirical literature on network effects and switching costs, we refer the reader to Farrell and Klemperer (2004).

The empirical studies that account for network effects in the telecommunications industry are relatively scarce. Most studies focus on the diffusion of telecommunications services and use reduced form regressions and diffusion models. The presence of network effects has usually not been taken into account. For instance, Gruber and Verboven (2001) estimate a logistic diffusion model for the EU countries and find that regulation and technological progress are important for the growth of mobile industry. Wallsten (2002) uses data on the telecommunications industry worldwide to analyze whether the sequence of reforms, such as establishing a regulatory authority and privatization of the incumbent, matters. Koski and Kretschmer (2005) analyze the effects of regulation and competition on the development of mobile telephony.

There are only a few recent studies which explicitly acknowledge network effects in the telecommunications industry. Bousquet and Ivaldi (1997) estimate network effects in fixed-line telephony in terms of usage. Kim and Kwon (2003) use a consumer survey to analyze Korean mobile telephony and conclude that consumers prefer carriers that have larger consumer bases. Birke and Swann (2004) use household survey data to identify price-mediated network effects in mobile telephony in the UK.

The paper most similar to ours is Grajek (2003) which estimates the magnitude of network effects in the Polish mobile telephone industry during the period 1996-2001. He essentially adopts the model of Katz and Shapiro (1985) and assumes that mobile services are homogenous and firms set equal hedonic prices. He adopts a quadratic network benefit function and allows the own and competitors' subscriber base to have a different effects on utility. He develops an estimating equation which explains the total subscriber base in each period. Estimating a system of such equations, he finds significant network effects which are mainly due to own installed base, despite full technological compatibility between the networks of different firms. Our model differs from Grajek (2003) in a number of aspects. We model services of different providers as differentiated products. More importantly, we posit a model of sales each period.

3.2 Mobile Telephony in Germany

3.2.1 Development of the Industry

The GSM and UMTS mobile telecommunications systems were preceded by a few technologically different analog networks – the first generation of mobile systems. The first commercial mobile telecommunications network in Western Germany was provided during the period 1958–1977 by the state-owned monopolist Deutsche Bundespost.

The so-called 'A-network' serviced about 70% of the country and amounted to only 11.000 users due to frequency limitations. In years 1972-1995, Deutsche Bundespost was providing mobile communications services though the 'B-network'. For the first time, roaming services in a few neighboring countries were offered. The total amount of users serviced on this network was approximately 27.000, which was again due to frequency limitations. The prices of mobile phones were very high and affordable only for well situated groups of the society.

The following 'C-network' was fully automated and used a SIM card to access the network. Again, it was provided by the state-owned monopolist Deutsche Bundespost-Telekom. This network was in use in years 1986-2000 and serviced a maximum of about 812.000 users. It was switched off after the introduction and successful development of second-generation digital networks.

The analog networks were followed by second-generation (2G) digital 'D-networks' (GSM 900) which started providing services in 1992. There were only two licenses granted – the first to the state-owned Deutsche Telekom Mobilnet which was later privatized and transformed into T-Mobile. The second license went to the first private mobile network operator Mannesmann Mobilfunk, which was later taken over by Vodafone. In 1993, a third license was granted to E-plus. Operation of this network at 1800 MHz frequency began one year later. Another license was granted in 1997 to Viag Interkom (later called O2) which started providing services in November 1998. In 1999, the 'D-networks' were granted transmission rights at 1800 MHz frequency as well.

In 2000 the German government auctioned licenses for third-generation mobile networks (UMTS) that allow for the transfer of data at much higher rates in order to satisfy the demands of multimedia applications. A total of DM 99 billion was paid by six companies for the rights to develop 3G networks: Group 3G (Quam), T-Mobil, Mannesmann-Vodafone, Auditorium, Mobilcom Multimedia and O2. These companies were established by consortiums of large multinational telecommunications companies and actual GSM network operators. The network development and the introduction of the 3G communications standard on the German market was expected to take place in years 2002-2005. One of the license winners, Quam, entered the market in November 2001 by signing roaming agreements with other network operators. It acquired about 200 thousand consumers but subsequently went bankrupt one year later.[3]

3.2.2 Market Structure

The network operators may sell services to consumers directly or indirectly through independent service providers (ISPs). In general, an ISP resells airtime on a third party's mobile network by providing billing and customer care services under the own brand name. In Germany, network operators can commercially decide whether to sign an ISP agreement. According to the German Telecommunications Act the agreements between the network operators and ISPs have to be non-discriminatory and assure fair competition between retailers. Typically, tariffs offered by the ISPs reflect tariffs of the network carriers.

In 2003 there were four network operators—T-Mobile, D2 Vodafone, E-Plus and O2—and about twelve ISPs in Germany. Of these four, only O2 has not reached an agreement with ISPs. Out of these firms, only eight had significant market shares – network operators: T-Mobil (29.9%), D2 Vodafone (27.7%), E-Plus (9.3%), O2 (6.3%) and ISPs: Debitel (12.7%), Mobilcom (6.5%), Talkline (3.2%), Drillisch (2.4%). The remaining ISPs accounted for only about 2.0% of subscribers.[4] The market share of ISPs has been decreasing over time. Because of data limitations and the aforementioned market structure we assume that consumers can only choose among network operators. Subscribers to ISPs are included into consumer bases of respective network operators.

Since the introduction of 2G networks, the mobile industry experienced dramatic growth rates. At the end of 2003, the number of mobile subscribers reached 64.8 million

[3]Source: "Connect" magazine, http://www.t-d1.de and http://www.xonio.de
[4]Source: www.RegTP.de

which implies a penetration rate of 78.3%. The distribution of market shares among four network operators remained stable in the last few years with T-Mobile maintaining about 40.6%, D2 Vodafone – 38.1%, E-Plus – 12.7% and O2 – 8.6% as of 3rd quarter 2003. Clearly, as the high market shares of T-Mobile and Vodafone suggest, early entry played a critical role for the size and growth of the consumer base. Late entrants E-plus and O2 applied innovative pricing policies but did not manage to enlarge their market shares substantially. For instance, since July 1999, O2 has been offering the Genion tariff. Under this tariff users pay fixed line rates for calls within at least one hundred meters around their declared home location and a lowered city tariff within the city area. Since December 1998, E-Plus has been providing a range of Time & More tariffs with free minutes and prices independent of call destination.

3.3 Empirical Model

We model demand for mobile subscriptions by a discrete-choice model, as discussed in Anderson, de Palma and Thisse (1992) and Berry (1994). We follow the estimation strategy proposed by Berry (1994) and invert market-share equations to find the implied mean levels of utility for each alternative. We then posit a functional form for this utility in terms of observed and unobserved variables. The unobserved variable serves as our econometric error term and is interpreted as the mean value of consumers' valuations for unobserved product characteristics, such as product quality, for instance.

We assume that all consumers have access to a fixed line. In the first stage they decide whether to continue using a fixed telephone alone or to buy a mobile as well. In the second stage the consumers choose a network operator. This is a standard nested logit structure, where one branch is degenerated and no further choices are made. The utility of an outside option for consumer i at time t is denoted by U_{i0t} and may vary in time due its dependence on prices of fixed line services, for instance. The utility derived by consumer i from using a fixed-line together with mobile services of network operator j can be written as

$$U_{ijt} = U_{i0t} + r_j - \alpha p_{jt} + V(z_t^e) + \zeta_{gt} + \xi_{jt} + (1-\sigma)\epsilon_{ijt} \tag{3.1}$$

where r_j is the stand alone value, p_{jt} represents service price and $V(z_t^e)$ is the expected network benefit, which we discuss in detail in the next subsection. The variable ζ_{gt} is a common value of all products in group $g = \{0, 1\}$ and has a distribution dependent on σ. The nest $g = 0$ stands for fixed line alone and $g = 1$ represents the choice of mobile telephony together with a fixed line. By normalizing with respect to the utility of the outside option, the choice of alternatives becomes independent of the determinants of the fixed line utility. The consumer's tastes for products within the nest may be correlated. When the choice of alternatives in the nest is independent, which implies that $\sigma = 0$, nested logit is reduced to a simple logit. Finally, ξ_{jt} accounts for the population average of the unobserved utility of operator j and ϵ_{ijt} is the idiosyncratic taste variable, which has a double exponential distribution.[5]

Following Berry (1994), we invert observed market shares to compute mean utility levels for each product and treat them as observed. Using the observed utility level and our specification in (3.1), we arrive at the following estimation equation

$$\log(s_{jt}) - \log(1 - s_t) = r_j - \alpha p_{jt} + V(z_t^e) + \sigma log(\overline{s}_{jt|g=1}) + \xi_{jt} \tag{3.2}$$

where s_{jt} represents the share of operator j in the total number of consumers that make decisions about the subscription and $s_t = \sum_j s_{jt}$. The share of operator j in the total sales of mobile services is denoted by $\overline{s}_{jt|g}$. The unobserved utility, ξ_{jt}, serves as the econometric error term.

[5]The only firm characteristics in the model are prices, stand alone values and unobserved qualities. The other potential choice determinants, such as the coverage and reception quality, were constant throughout the time of this study. An exception is O2, which had smaller network coverage right after the entry in November 1998 but is excluded from this analysis for the reasons discussed in the next section. According to tests carried on by telecommunications magazine "Connect" from 30.11.2000, the networks are hardly distinguishable in the coverage and reception quality.

The specification of utility function (3.1) is representative of consumers with sufficiently low (zero) switching costs and of new consumers. Otherwise, the utility function may depend on the previous choice due to switching costs, for instance. Because we miss precise data on the number of switching consumers and their choices of network operators, we have to make simplifying assumptions. We assume that there are three types of consumers. Consumers with sufficiently low switching costs and new consumers choose network operators, while consumers with high switching costs are locked-in and continue using the same mobile services. Hence, they are assumed to be out of the market and are excluded from the computed market sizes. We use data on accumulated subscriptions and churn rates to approximate the locked-in consumers.[6] One can compute the sales of an operator in a given period by the first difference of the observed number of subscribers and the number of locked in consumers. That is, sales of operator j in period t can be approximated by the difference $y_{jt} = Z_{jt} - (1 - \lambda_{jt})Z_{jt-1}$ where Z_{jt} stands for the number of subscribers and λ_{jt} represents the churn rate.[7] The total number of consumers who can make subscription decisions is given by $m_t = M_t - \sum_{j=1}^{N}(1 - \lambda_{jt})Z_{jt-1}$, and represents our market size. Here, M_t is the total market size in period t, including the locked-in consumers. Only the consumers over an age 16, that is 84% of total population, are considered.[8] Thus, the share of subscribers of network operator j in the total number of consumers that can make subscription decisions is given by $s_{jt} = y_{jt}/m_t$. The share of the outside good is computed as $s_{0t} = 1 - s_t = 1 - \sum_{i=1}^{N} s_{jt}$.

3.3.1 Network Effects in Mobile Telephony

So far we have not specified how consumers form expectations about network size and how the network benefit function is formulated. Most of the empirical and theoretical

[6] We are very grateful to Jan Kranke for providing us with data on approximate quarterly churn rates for network operators in Germany. We calculate monthly data by linear approximation.

[7] This approximation implicitly assumes that all consumers of a given firm with zero switching costs buy other alternatives, and hence can be fully accounted for by the churn rate.

[8] The estimation results are robust with respect to the market definition.

literature on network effects assumes linear network benefits. Swann (2002) examines the assumptions on communications needs which are necessary for the utility function to be either linear or s-shaped in the network size. He argues that an s-shaped utility function in the network size is more realistic for an average consumer and that the shape may differ for pioneers, medium adopters and late adopters. In the time period considered in this study, the mobile telephony market in Germany was in its fastest growth phase. Thus, the network benefits should be well approximated by a simple linear function $V(z_t^e) = \beta z_t^e$. We provide a test which supports the linear specification compared to a more general model where network benefit function is assumed to have a Box-Cox form.

We employ a very simple rule for the formation of expectations. We assume that consumers think that the network penetration in the last period will be realized in the current period. When the market reaches a steady state, such formation of expectations will be fulfilled. Networks are fully compatible and their users may freely communicate with each other. Thus the expected penetration is represented by the sum of lagged installed bases divided by the size of population, $z_t^e = \sum_j Z_{jt-1}/M_{t-1} \equiv z_{t-1}$. A new subscriber to any of the networks brings the same marginal utility.

Clearly consumers derive network benefits from a fixed line network as well. In the last decade, however, changes in the number of subscribers to fixed line telephony were negligible. Given our assumption regarding the linear network benefit function and the linear form of utility function in (3.1), any network benefits from the fixed line are cancelled when we normalize with respect to the outside option. Furthermore, there may also be asymmetric own and cross-network effects due to the differences in on-net and off-net prices. We test for this possibility, and find that our data does not support network effects with different magnitudes.

3.4 The Data

The data on mobile subscriptions is collected from the Internet site of the German regulator – RegTP. The subscription data is available from June 1992, but we restrict this analysis to the period for which we could collect prices. As a result we have 66 monthly observations from January 1998 to June 2003. Because of the late entry of the fourth network operator O2 in November 1998 and its small market share at the end of the analyzed period (8,6%), it may be difficult to estimate demand for this operator. In this study we only estimate demands for three main network operators, which in total cover about 91% of the market: T-Mobile, D2 and E-Plus.

For the purpose of this study we need firm-specific prices. We collected tariff information from the price listings published in telecommunications magazines and on the Internet in the time period January 1998 – June 2003. We applied the methodology used by the statistical office to compute firm-specific indices.[9],[10] First we assume infrequent usage behavior and calculate expected monthly bills for all tariffs provided by network operators. In addition to what the statistical office does, we assume some randomness in calling behavior. Hence we randomize the number and length of phone calls as well as the distribution of calls among destination networks and time-zones. The distribution among destination networks is proportional to the market shares. Moreover we account for price discrimination between on-net and off-net calls, which is omitted in the computation of official indices. We simulate 200 bills for each tariff and compute the mean values to compare tariffs. Out of the set of tariffs offered by each network operator, we pick the tariff which delivers the lowest bill. The cheapest

[9]The German statistical office computes four monthly price indices for mobile services. First, three consumer profiles are defined based on the consumption intensities: infrequent, average and frequent users. Typically, network operators provide a set of tariffs for each profile. For all tariffs within each profile, an expected monthly bill is calculated. Consumers are assumed to be perfectly informed about the range of tariffs available each month on the market and choose the cheapest one. In this way, three profile indices are created which are further used to calculate aggregate weighted price index for mobile services. Tariffs consist of many price factors, such as on-net, off-net, fixed-line, time zones, billing intervals and so on: But the statistical office uses only the most important ones in the calculation. See Statistisches Bundesamt Wiesbaden, 1999.

[10]Source: magazine "Connect", http://www.teltarif.de

tariff for the infrequent user is the one, which determines the subscription decision of the marginal consumer.

The price indices computed in this way are correlated with the official price indices provided by the statistical office. Figure (3.1) presents changes in the minimum tariffs for an infrequent user during the time period of this study. Apart from prices, firms also compete in handset subsidies and often provide handsets for free. For instance, in June 2003, T-Mobile offered six different handsets for the price of 1 Euro, D2 – ten handsets, E-Plus – eight handsets and O2 – seven handsets.[11] Network operators try to recoup the initial investment in consumers through a stream of future payments.

3.4.1 Instrumental Variables

To account for the endogeneity of prices and the within group shares we use instrumental variables. We have to find instruments which are correlated with prices and within group shares, but uncorrelated with the unobservable demand shocks. The error terms may be autocorrelated due to the character of data. Thus the usage of lagged endogenous variables, such as lagged consumer base, could be problematic.

Apart from the lagged installed base, we use only one exogenous variable in the model – a dummy for Christmas sales. This may be a good instrument for prices. Firms tend to offer special Christmas deals resulting in peak mobile sales in November and December. At the start of the year, due to the preparation for the main telecommunications fair – CeBIT, firms tend to make announcements of new tariffs. This fair is held in Hannover in early March. Thus the first quarter dummy may be used as an instrument for prices.

Other candidates for instruments could be proxies for cost factors. For instance, Evans and Heckman (1983) estimate the total cost function in fixed line telephony using input prices as cost determinants. Input prices include the price of materials, the price of capital and the wage rate. The only instrument we use here is the cost of

[11] Source: "Connect" magazine, June 2003

the telecommunications equipment, as provided by the German statistical office. The correlation coefficient of prices for mobile services with the index of hourly wages in the telecommunications industry is almost zero.

The time trend, which accounts for the technological innovation in mobile telephony, may be a component of the cost function as well. It could be interpreted as a constant upgrade in the quality of services and handsets. Furthermore the entry of Viag, which took place in November 1998, could have decreased market prices. We use the number of tariffs offered by network operators as an instrument for the within group shares. Potentially, the variation in the number of tariffs should affect the within group shares.

Unfortunately we miss any other firm-specific variables. We use the following set of instruments $W_t = [1, christmas_t, quart1_t, capital_t, time_t, viag_t, tariffs_{jt}]$. Our identifying assumption is the mean independence of the demand shocks in (3.2) with the set of instruments, i.e. $E(\xi_{jt} \mid W_t) = 0$.

3.5 Estimation Results

The demand for mobile subscriptions is dependent on service prices, the lagged total installed base and a dummy for Christmas sales. The coefficients for price and network benefits are assumed to be the same for all three networks. However, the Wald test rejects the equality of demand intercepts (see Table 3.1).

First, demands are estimated using ordinary least squares (OLS) and two stage least squares (2SLS) with the set of instruments discussed in the previous section. The estimation results are presented in Table (3.1). According to the Hausman specification test, the null hypothesis of the exogeneity of prices may be rejected at a significance level of 10%. The Breusch-Godfrey test indicates autocorrelation of the error terms in all three demand equations. We account for the problem of endogeneity and autocorrelation by estimating the parameters using general method of moments (GMM) with the Newey-West estimator for the covariance matrix of the moment conditions.

We also estimated two different versions of the model to check the robustness of our results. The first extension considers differential magnitudes of own and cross network effects. Estimating demand functions that include both own and cross installed bases as explanatory variables turns out to be impossible due to the high correlation of subscriptions. Hence we fix the estimate of the own network effects to the value from our preferred specification (column III in Table 3.1) and test whether the cross network effects are significantly different. In this case the estimate of cross network effects is given by $\beta_0 = 1.72$ (column IV in Table 3.1). The Wald test statistic of 4.44 implies that we cannot reject the equality of own and cross-network effects at a significance level of 1%.[12] Therefore, network effects resulting from the total installed base seem to be a justified assumption.

Our second extension considers a possible nonlinearity of the network benefit function. Similar to Clements and Ohashi (2004), we use a Box-Cox transformation of the lagged penetration of mobiles and specify the modified network benefit function as $V(z_t^e) = \beta\frac{(1+z_{t-1})^{\lambda}-1}{\lambda}$. This transformation allows for our linear specification when $\lambda = 1$ and logarithmic when $\lambda = 0$. Once again, due to a collinearity problem, we are not able to estimate β and λ simultaneously. Again we fix the coefficient of network effects β and estimate λ. The hypothesis that $\lambda = 1$ cannot be rejected, which supports the use of a linear network benefit function (Wald test statistics of 0.42). Also Clements and Ohashi (2004) cannot reject the hypothesis of a linear specification for indirect network effects.

The estimates of all parameters are significant, as presented in Table (3.1). In particular, σ is estimated to be 0.80, which implies a relatively high correlation of choices within the nest. We calculate the elasticities of demand to interpret the estimates of coefficients for price and network effects. The own and cross price elasticities of

[12]Note that when we computed firm specific price indices, we took the difference in on-net and off-net prices into account. Thus, any price mediated network externality is already captured in the price indices.

demand in the nested logit model are specified as

$$E^{s_{jt}}_{p_{kt}} = \begin{cases} -\frac{\alpha}{1-\sigma} p_{jt} \left[1 - \sigma \overline{s}_{jt|g=1} - (1-\sigma) s_{jt}\right] & \text{if } k = j; \\ \frac{\alpha}{1-\sigma} p_{kt} \left[\sigma \overline{s}_{kt|g=1} + (1-\sigma) s_{kt}\right] & \text{if } k \neq j. \end{cases}$$

where s_{jt} is the share of network operator j in sales at time t and $\overline{s}_{jt|g=1}$ is the within group share. Table (3.2) presents the average elasticities for GMM estimates for period January 1998 – June 2003. We also calculate the elasticity of demand for mobile services in total, which is given by

$$E^{s_t}_{p_{jt}} = -\alpha s_{jt}(1 - s_t)\frac{p_{jt}}{s_t}$$

The values in Table (3.2) are interpreted as follows: on average in the period January 1998 – June 2003, a 1% price increase by T-Mobile resulted in 0.52% decrease in total sales. Similarly, a 1% price increase by D2 and E-Plus led to a decrease in total sales by 0.52% and 0.19%, respectively. The elasticity of demand for mobile services in respect to the past installed base is specified as

$$E^{s_t}_{z_{t-1}} = \beta z_{t-1}(1 - s_t).$$

If the previous period total installed base increased by 1%, current period sales would surge on average by 0.69%. This indicates strong network effects. If there were no network effects, the industry growth would be stimulated only by price changes. As presented in Figure (3.1), the penetration level in the absence of network effects could be at least 50% lower, compared to the current case. This is due to the fact that prices remained almost constant in the second part of the period analyzed. Network effects also have an impact on the equilibrium prices, which is ignored in projections. In the absence of network effects, the current penetration level could be reached only if prices were significantly lower. Figure (3.1) suggests that prices would have to fall to zero or even lower. These projections indicate the importance of network effects for the growth of the industry. There was also a significant Christmas effect which resulted in an increase in demand for mobile subscriptions during the months of November and December.

Furthermore, assuming that observed prices are the result of a pure strategy Nash equilibrium, we can make use of the first-order equations to retrieve information about marginal costs. This assumption ignores the effects of current prices on future profits, which potentially leads to overestimated markups. The estimates of markups may be interpreted as an upperbound. Following Berry (1994), using first-order conditions for the nested logit model, the marginal cost may be written as

$$c_{jt} = p_{jt} - \left[\frac{(1-\sigma)}{\alpha} \Big/ [1 - \sigma \overline{s}_{jt|g=1} - (1-\sigma) s_{jt}] \right] \tag{3.3}$$

Using the estimates of α and σ from the demand side we may calculate the changes in marginal cost and markup for each network operator over the time period analyzed. Figure (3.1) shows changes in the Lerner index calculated as $(p_{jt} - c_{jt})/p_{jt}$. The Lerner index for all network operators increased over time from about 13% in January 1998 to about 30% in June 2003. This increase is due to the fact that the margins remained almost constant while the prices decreased. The Lerner index at the end of the period differed across network operators with E-plus having the lowest value of about 28%, T-Mobile roughly 31% and D2 approximately 36%.

3.6 Conclusion

In this paper we analyze the role of network effects in the mobile telecommunications industry in Germany. We find that network effects have a significant impact on consumers' decisions regarding subscriptions to mobile telephony. We are able to disentangle the impact of price and network effects on subscription demand and estimate reasonable price elasticities. On average in the period January 1998 – June 2003, a 1% price increase by T-Mobile resulted in 0.52% decrease in total sales. Similarly, a 1% price increase by D2 and E-Plus led to a decrease in total sales by 0.52% and 0.19%, respectively. If the previous period total installed base increased by 1%, current period sales would surge on average by 0.69%. If there were no network effects, the penetration of mobiles at the end of the period analyzed could be at least 50% lower. Current penetration levels could be reached only if prices were drastically lower. Furthermore, by estimating the price coefficient and assuming Nash equilibrium in prices we could provide measurements of marginal costs.

3.7 Appendix

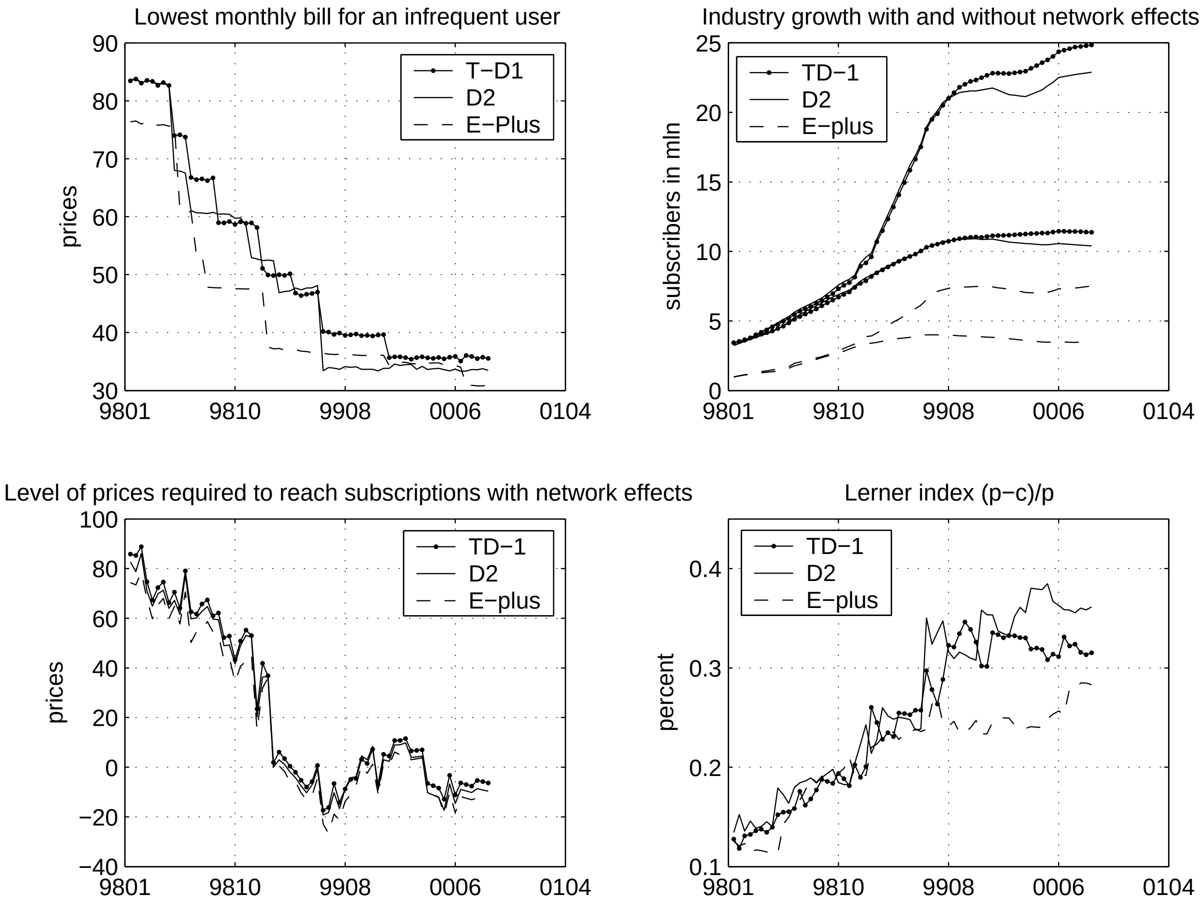
Table 3.1: Nested logit – T-D1, D2 Vodafone, E-plus

Name	OLS Est. (t)	2SLS Est. (t)	GMM Est. (t)	GMM own Est. (t)	GMM bc Est. (t)
r_{d1}	-2.62 (-8.77)	-2.83 (-8.40)	-2.92 (-21.68)	-3.03 (-37.77)	-2.84 (-27.13)
r_{d2}	-2.69 (-9.24)	-2.89 (-8.81)	-2.98 (-22.46)	-3.08 (-40.14)	-2.90 (-28.14)
r_{e1}	-2.96 (-8.68)	-3.21 (-7.43)	-3.28 (-30.34)	-3.32 (-40.71)	-3.24 (-38.30)
β	1.34 (6.09)	1.40 (5.17)	1.47 (10.23)	1.47	1.47
β_0				1.72 (14.49)	
α	-2.46 (-8.40)	-2.27 (-6.44)	-2.16 (-15.14)	-1.98 (-21.55)	-2.28 (-17.44)
Christ.	0.31 (4.78)	0.31 (4.85)	0.33 (4.84)	0.36 (4.89)	0.33 (4.88)
σ	0.85 (6.57)	0.79 (3.49)	0.80 (23.34)	0.89 (29.49)	0.76 (20.78)
λ					0.82 (3.03)
mse td1	0.1073	0.1090	0.1098	0.1105	0.1081
mse d2	0.1193	0.1196	0.1199	0.1200	0.1190
mse e1	0.1002	0.1000	0.1000	0.1004	0.0995
N*obj.	20.80	6.1479	12.2979	11.9607	12.3651
Hausman		12.55			
$Pr > \chi^2$		0.0840			
Wald			171.29	4.44	0.42
$Pr > \chi^2$			0.001	0.035	0.51

Table 3.2: Demand elasticities – prices and past consumer base

	T-Mobile	D2	E-Plus	Mobiles s_t
T-Mobile	-4.48	2.22	2.22	-0.52
D2	2.19	-4.20	2.19	-0.52
E-Plus	0.79	0.79	-5.04	-0.19
Network effect				0.69

Figure 3.1:


Lowest monthly bill for an infrequent user
prices
T−D1
D2
E−Plus
90
80
70
60
50
40
30
9801
9810
9908
0006
0104
Industry growth with and without network effects
subscribers in mln
TD−1
D2
E−plus
25
20
15
10
5
0
9801
9810
9908
0006
0104
Level of prices required to reach subscriptions with network effects
prices
TD−1
D2
E−plus
100
80
60
40
20
0
−20
−40
9801
9810
9908
0006
0104
Lerner index (p−c)/p
percent
TD−1
D2
E−plus
0.4
0.3
0.2
0.1
9801
9810
9908
0006
0104

Chapter 4

Estimating Switching Costs in Mobile Telephony in the UK

4.1 Introduction

When consumers terminate their current relationship with a seller, they have to bear one-time switching costs. An important implication of switching costs is that homogeneous products ex-ante become heterogeneous after the purchase.[1] Switching costs provide firms with market power because consumers will switch only if competitors charge lower prices. The existence of switching costs is a focal point in many antitrust cases and in regulation policy. Thus, identifying and measuring switching costs may support the policy makers by indicating whether there is a potential for abuse of market power and inefficiencies in consumers' choices.

Mobile telephony is an example of an industry in which consumers are believed to have high switching costs, for instance, due to compatibility costs, transaction costs or search costs. The first one arise when operators lock handsets to be used exclusively within their own networks. In this way, consumers are prevented from switching to another network after getting a subsidized handset. Transaction costs arise when con-

[1] Klemperer (1995) provides a general explanation of the sources of switching costs.

sumers change the telephone number after switching network operator. Some effort is required to distribute a new telephone number among friends. Alternatively, the number may be ported which in reality can also be costly for consumers. Finally, search costs arise because consumers have to gather information about other networks.[2]

The regulators of the telecommunications industry assume that switching costs are present and introduce regulation which aims to decrease them. The prime way of decreasing transaction costs is by implementing portability of numbers. Number portability in the UK was introduced in January 1999. Compatibility costs may be reduced by prohibiting handset-locking. Lack of intervention by the British regulator Oftel (later renamed to Ofcom) in this matter is due to the belief that prohibition of handset-locking would have zero effect on the competition and consumers' switching behavior.[3] Finally, search costs could be decreased by providing consumers with comprehensive information about all services that are available on the market. The British regulator provides consumers with recommendations about the choice of mobile services. There are also plenty of commercial online services which provide support in making the choice of network operator, tariff and handset.

Restraining from taking the presence of switching costs in mobile telephony as given, this paper provides an empirical test whether consumers have disutility from switching network operators. For that purpose it uses uses survey data on British households (Home OnLine) between the years 1999-2001. According to mixed logit estimates for panel data there are significant negative switching costs which vary across network operators. The choices of network operators are also explained by observable and unobservable heterogeneity of tastes. The observable heterogeneity is represented by consumer characteristics, such as: gender, age and employment status. When multinominal logit is estimated switching costs are overestimated due to ignorance of unobservable tastes. Thus, this study indicates the importance of unobservable heterogeneity of tastes in the estimation of switching costs. Both switching costs and

[2] For detailed discussion see NERA, 2003. "Switching costs".

[3] Oftel, Review of SIM-Locking policy, 26 November 2002.

persistent tastes of consumers lead to state-dependent choices of network operators. Furthermore, the estimation of logistic regression indicates that the probability of switching depends on consumer characteristics, such as age, usage intensity and ways of spending leisure time. These results are consistent with the findings in the consumer surveys conducted by the British regulator Oftel.

The next section provides an overview of empirical literature on switching costs. Section 3 briefly presents the mobile telecommunications industry in the UK. Section 4 presents the empirical model, describes the estimation methodology and data. Section 5 discusses estimation results. Finally, section 6 concludes the analyzes.

4.2 Literature

There is an exhaustive body of theoretical literature on switching costs. The number of empirical studies is scarcer which is mainly due to lack of appropriate data on the purchase history of individuals. Following the methodology used in the report prepared by NERA for the British Office of Fair Trading, the empirical methods for estimating switching costs may be divided into indirect and direct.[4] Indirect methods use aggregate data to identify switching costs, usually by estimating reduced-form pricing equations. For instance, Borenstein (1991) measures the magnitude of switching costs in the U.S. retail gasoline market. Knittel (1997) analyzes the changes in prices for long distance telephone calls in the U.S. after AT&T divestiture in 1984, and explains price rigidity by the presence of search and switching costs. Viard (2002) studies the impact of the introduction of number portability on prices for toll-free numbers in the U.S. He finds that when firms cannot discriminate between old locked-in consumers and new ones, switching costs may have an ambiguous effect on prices. Several other empirical studies provide evidence for the presence of switching costs in a range of industries, such as banking loans, credit cards, electricity, airlines, computer software,

[4] NERA, 2003. "Switching costs".

television and others (for a review and a list of references see Farrell and Klemperer (2004)).

Direct methods use information on individual consumer choices and employ random utility framework. There are very few studies of this type. For instance, Chen and Hitt (2002) use household data to estimate the magnitude of switching costs and brand loyalty in the online brokerage industry. They find that consumers' switching costs vary across firms which may control their magnitude through adequate product design and retention strategies. Epling (2002) studies competition in the long distance telephony market in the U.S. after 1996. She finds empirical evidence for the heterogeneity in the subscriber switching costs and concludes that consumers with high switching costs end up paying higher prices. Shum (2004) estimates switching costs using panel data on households' breakfast cereal purchases. Apart from the economic literature, there is a growing number of related marketing studies on brand loyalty and state dependence in consumer choices.

One important issue which arises when the state dependence of choices is estimated directly, is that consumers could have unobservable persistent heterogeneous preferences. Heckman (1981) draws a difference between true state dependency and spurious state dependency. True state dependence is a consequence of all observable factors which can be switching costs and brand loyalty. Spurious state-dependence results from persistent heterogeneity in the preferences for brands. Consumers may continue buying the same product because it fits better with their idiosyncratic tastes. Hence, the parameters representing switching costs may be overestimated when spurious state dependence is ignored. There is a large body of empirical studies which try to separate true and spurious state dependence. Among studies specifically on switching costs, Chen and Forman (2003) suggest two strategies to separate switching costs from spurious state dependence. They employ an instrumental variable approach and mixed logit estimation, and their findings show high switching costs in the market for routers and switches. Goldfarb (2003) measures loyalty for Internet portals controlling for household-specific heterogeneity by estimating a separate regression for each household. Shum (2004) accommodates unobserved heterogeneity via random effects.

This study estimates switching costs directly using data on individuals' choices of network operators in mobile telephony. Mixed logit is estimated in order to account for the unobservable consumer heterogeneity. The estimation results indicate that both switching costs and persistent tastes lead to state-dependent choices of network operators. Thus, when unobservable tastes are ignored, switching costs are overestimated.

4.3 Mobile Telephony in the UK

Currently, the mobile telecommunications industry in the UK is represented by five network operators: Vodafone, BT Cellnet (later renamed to O2), One2One (later renamed to T-Mobile), Orange and Hutchinson 3G. The first four operators provide services in the GSM technology, while Hutchinson 3G is one of the UMTS licence winners and started to provide 3G services in 2003. Vodafone and BT Cellnet launched their networks in 1985 (analog at first). Orange and One2One entered the market in 1994. Until their entry, Vodafone and BT Cellnet were prohibited from supplying services directly to consumers. They had to establish subsidiaries dealing with retail sales and were obliged to provide wholesale airtime to independent service providers (ISPs). ISPs do not possess network infrastructure but provide billing and customer care services under own brand names. Later on, Vodafone and BT Cellnet were designated by Oftel as having significant market power in the retail market. Again they were required to provide wholesale airtime to ISPs. Orange and One2One were not obliged to do this. ISPs are not considered in this analysis. Thus, the number of choices is restricted to four network operators because the survey was conducted before the entry of Hutchinson 3G.

4.4 Empirical Analysis

4.4.1 Estimation Methodology

In the present study, the choices of network operators are modelled by employing the random utility framework developed by McFadden (1974). In this approach individual utility functions are estimated by assuming utility-maximizing heterogenous consumers. The utility function includes observable choice determinants and a stochastic component which represents unobservable idiosyncratic preferences. Consumer's valuation of the product typically depends on its price and other attributes as well as on consumer demographics. When switching costs are present, the previous choice influences current utilities. Switching costs cause a bias in the consumer preferences towards the alternative which was chosen before. However, the choice may also be state-dependent due to persistent consumer tastes which are unobserved by the econometrician.

All surveyed consumers have access to a fixed line and noone gives up fixed line connection throughout the survey period. Thus, they decide whether to continue using a fixed telephone alone or to buy a mobile as well. The utility of an outside option for consumer i at time t is denoted by U_{i0t} and can vary in time due to its dependence on prices of fixed line services. The utility derived by consumer i from using a fixed-line together with mobile services of network operator j out of J operators available on the market may be written as:

$$U_{ijt} = U_{i0t} + r_j + \alpha p_{ijt} + \beta x_{jt} + \gamma_j z_{it} + \sum_{k=1}^{J} w_k s_{ijkt} + \xi_{ij} + \epsilon_{ijt} = V_{ijt}(\xi_{ij}) + \epsilon_{ijt} \quad (4.1)$$

By normalizing with respect to the utility of the outside option, the choice of alternatives becomes independent of the determinants of the fixed line utility. In general, the utility of mobile telephony can be determined by individual specific service price p_{ijt}, network attributes x_{jt}, a firm-specific dummy r_j and consumer demographics z_{it}. A set of dummies s_{ijkt} accounts for switching from alternative k to alternative j. These variables are constructed as follows: a dummy s_{ijkt} takes value zero if consumer i has chosen the same network operator $j = k$ in the previous period $t-1$ and one otherwise. For consumers which did not make any choice in the previous period, the value of s_{ijkt} is equal zero.

$$s_{ijkt} = \begin{cases} 0 & \text{if j=k or consumers are new that is k=0} \\ 1 & \text{otherwise.} \end{cases}$$

The persistent consumer heterogeneity is represented by ξ_{ij}. Finally, ϵ_{ijt} is the idiosyncratic unobservable taste variable which captures the effects of other unmeasured variables. The parameters in front of consumer demographics γ_j account for observable consumer heterogeneity. The coefficients for switching dummies w_k represent the disutility which the consumer bears when changing network operator. In formulation (4.1), the disutility from switching operator depends on the network from which consumers switch. Each network operator employs a different policy towards switching consumers. For instance, there may be differences regarding the cost of unlocking the handset or porting the number. Moreover, artificial switching costs can also vary across networks, such as an ongoing loyalty program or psychological costs when consumers are uncertain about the quality of other networks. Alternatively, switching costs could be assumed to be the same across networks. The disutility from switching can also be heterogenous across consumers, that is, random coefficients for switching dummies could be estimated.

Consumers maximize utility and choose network operator m with the greatest value among all alternatives, $U_{imt} \geq max_{j \in C_i, j \neq m} U_{ijt}$, where C_i is the choice set of individual i. When there is no persistent consumer heterogeneity ($\xi_{ij} = 0$) and the stochastic utility component ϵ_{ijt} is distrtibuted independently and identically extreme value, the choice probabilities simplify to closed-form multinominal logit expressions

$$P_{imt} = P[V_{imt} + \epsilon_{imt} \geq max_{j \in C_{it}, j \neq m} V_{ijt} + \epsilon_{ijt}] = \frac{\exp(V_{imt})}{\sum_{j \in J} \exp(V_{ijt})} \tag{4.2}$$

The iid assumption about ϵ_{ijt} implies proportional substitution across alternatives and is inappropriate in many situations. In this case, the outside option – fixed line telephony – is assumed to be an equal substitute to mobile services. The iid assumption enters also for choice sequences made by the consumer over time. Thus, the choice probabilities for panel data are derived exactly in the same way as for the cross section. In many cases choices are correlated over time and when the spurious state dependence is ignored, the coefficients for switching costs w_k could be overestimated.

Mixed logit gets over this constraint by decomposing the unobserved factor into two parts. The first one contains all the correlation and heteroskedasticity, and the second one is iid extreme value distributed. The first unobserved component may follow any distribution: lognormal, uniform, triangular, gamma or any other. When explanatory variables and density are appropriately specified, any utility-maximizing behavior could be represented by a mixed logit model, in particular nested logit (see Train (2003) for further discussion).[5] In the present case, ξ_{ij} are assumed to have joint normal density. The choice probabilities have no closed-form expressions and are given by:

$$P_{imt} = \int_{\xi} \left[\frac{\exp(V_{imt}(\xi_{im}))}{\sum_{j \in J} \exp(V_{ijt}(\xi_{ij}))} \right] f(\xi) d\xi. \tag{4.3}$$

[5] In the case of mobile telephony, nested logit represents a plausible pattern of consumer choice. In the first stage consumers choose between having fixed line only and fixed line together with mobile. In the second stage they select one out of four mobile operators (see Chapter 3). Thus, the mobile networks are closer substitutes than fixed line. Nevertheless, the mixed logit model estimated in this study is more general than nested logit.

The log-likelihood function for mixed logit equals to:

$$LL(\cdot) = \sum_i \sum_j \sum_t y_{ijt} \log(P_{imt}),$$

where $y_{ijt} = 1$ if consumer i chooses alternative j in month t and 0 otherwise.

When dynamic choice models are estimated, an important issue to account for is the initial conditions problem. The choice probabilities in the first observed period depend on the choices in the earlier periods which are not observed. The probabilities for the first choice must be somehow determined. The ways of dealing with this problem are addressed by Heckman (1981a, 1981b) and Wooldridge (2002). As argued in the next subsection, the initial conditions problem may be ignored in the present case. This is due to the fact that for most consumers their first choice of mobile operator is included in the data.

Besides estimation of simple logit model (4.2) and simulated mixed logit (4.3), consumer's decision whether to switch network operator could be regressed on firm dummies and consumer characteristics, as given by following logistic regression:

$$log\left[\frac{P_{it}(switch)}{1 - P_{it}(switch)}\right] = \sum_j \beta^s r_j + \gamma^s z_{it} + \omega_{ijt} \tag{4.4}$$

4.4.2 The Data

The data used in this paper is based upon the British households survey Home OnLine which is available for research purposes through the Institute for Social and Economic Research at the University of Essex. It was conducted on a representative sample of British households. The aim of the survey was to gather individual and household level data about the use of information and communications technologies. The data consists of three annual waves: October-December 1998, January 2000 and February 2001. The first wave comprises 1000 households with response rate of 57%. Households that dropped out in the next waves were replaced by new ones. The response rate accounted for 75.7% and 67.1% respectively in the second and third wave.

Not all respondents provided information about the use of mobile services. For instance, in the first wave, out of 2608 individuals, 478 declared to have mobile phones and 1315 not to have them (penetration rate 26.66%). In the second and third waves, the respective numbers were: 2555, 844, 725 (53.79%) and 2406, 1106, 450 (70.99%). According to ITU statistics mobile penetration rates in the UK at the end of respective years accounted for 25.11%, 45.68% and 72.70%. Thus, the penetration in the group of people which answered the question about mobile subscriptions seems to be accurate.[6]

In the second wave, 239 individuals were subscribed to mobile services in both first and second waves, 480 remained unsubscribed in both waves, 292 started using mobile services in the second wave and 22 resign from the usage of mobiles (see Table 4.1). In the third wave, 573 declared their network operators both in the second and third waves. In the group of 558 consumers which declared no subscription to mobile services in the second wave 320 remain unsubscribed and 238 started using mobiles in the third wave. Finally, 22 consumers gave up the usage of mobiles in the third wave.

There were 613 consumers which declared not to have mobile phone in the first wave, and they provided information about their further choices both in the second and third waves. The amount of consumers which provided information about the network operator of their choice in all three waves looks as follows: 64 consumers of BT Cellnet, 29 of Orange, 77 of Vodafone and 17 of One2One. Table (4.2) presents tracking of consumer choices over all three waves.[7]. Altogether in this analysis I used 2078 consumers of whom 692 provided information about usage of mobile services in the one wave only (33.3% of all), 586 in two waves (28.2%) and 800 in all three waves (38.5%).

For majority of consumers, as shown in Table (4.2), the first ever choice of network

[6] The penetration rates within the total sample account for 18.3% in year 1998, 33% in year 2000 and 46% in 2001. Thus, many consumers who did not mark any answer had mobile phones.

[7] The sample used in this study is representative for the whole database which is checked using basic comparative statistics in Table (4.5)

operator is contained in the data.[8] When the choices are observed from the beginning, the initial conditions problem does not arise and mixed logit may be used to capture state-dependence in dynamic models (see Train (2003)).

4.4.3 Choice Determinants

One may refer to surveys conducted by Oftel to determine factors that could influence the choice of network operator. According to the survey from February 2002, around 59% of consumers indicated the cost of using mobile services as the critical choice factor. Followed by this are the coverage and reception quality mentioned by 21%.[9] The percentage of consumers which take these factors into account is relatively small which indicates that consumers perceive the coverage and reception quality to be the same for all network operators. According to official statistics provided by Oftel, the differences in coverage and reception quality across networks are negligible. Table (4.3) presents results based on call success rate survey conducted between October 1999 and March 2000 showing small variation across all regions. Based on this table, the impact of these factors is equivalent to adding a constant to each utility function, except the fixed line, that is $\beta x_{jt} = \beta x_t$, and as such cannot be identified in the estimation.

Firms set different prices for consumers with different usage intensity. Hence, there is no single price for all consumers, but rather a set of prices targeted at segments of consumers. Table (4.4) presents the prices for representative tariffs for two different usage patterns based on a study conducted by Oftel. For any consumer with certain

[8] 1278 consumers had no mobile phone in the first wave and 148 consumers for whom the first wave information is missing had no mobile phone in the second wave. Among the other 205 individuals which did not provide any information about the usage of mobiles in the first wave, statistically about half were not subscribed to any network in the first wave. This is because the mobile penetration was about 46% in 1999 and 25% in 1998. Still, there is a group of 446 consumers which declared usage of mobile services already in the first wave. However, the penetration of mobiles a year before was around 13-14% compared to 25% in 1998. Thus, within this group statistically around 230 consumers made their first choice in the first wave. Altogether, there may be about 330 consumers out of 2078 for whom their first choice of network operator is not observed. The results of this study should not be significantly influenced by the assumption that the first declared choice of these 330 consumers is their first choice of network operator at all. This assumption eventually leads to underestimation of switching costs.

[9] Consumers use of mobile telephony, Oftel, Q8 February 2002

usage pattern, given small differences in monthly costs, the expected cost of using mobile services provided by any network operator could be assumed to be equivalent. In particular, adding some uncertainty and randomness in the intensity of usage, monthly bill values presented in Table (4.4) would not be distinguishable. Since only differences in utilities matter, price coefficient α cannot be identified.[10]

Summing up, consumer choice is determined by consumer demographics, switching costs and some unobserved factors. Firm dummies can differ significantly across networks because of differences in brand values and other factors, such as network effects.[11] Any potential price differences may also show up in the firm dummies. Consumer characteristics represent observable heterogeneity of tastes and determine a match between consumer preferences and service offered by particular operators. Following variables are used in the estimation: gender, age and employment status (see Table 4.5 for simple statistics).[12]

Finally, the list of consumer characteristics which influence switching between networks is given in Table (4.7). All variables take ordered discrete values, except the employment status. Dummies for being employed, retired, full-time student or at school and unemployed are used in the regression. The unemployment dummy includes all other categories, such as: on maternity leave, looking after family or home, long term sick or disabled, on a government training scheme, etc.

[10]It is clearly a very strong assumption that each consumer perceives prices of mobile services set by different network operators as equal. There is no empirical evidence in support of this assumption. However, some very weak test can be performed based on available data. The cost of using mobile services reported by some individuals in the survey may be regressed on consumer demographics and firm dummies. Firm dummies turn out to be insignificant in such regression which means that on average the bill value is independent on network operator.

[11]Even though all networks are fully compatible, there may be asymmetric network effects due to the differences in on-net and off-net prices which make larger networks more attractive. Birke and Swann (2004) use the same Home OnLine survey data, together with market-level data on prices and call traffic, to identify price-mediated network effects.

[12]Some other consumer characteristics could also explain heterogeneity of tastes, but these are not available for all three waves. For instance, variables, such as: the number of local and non-local friends and relatives, and hours spent weekly on housework significantly determine choice of network operators when multinominal logit is estimated for the third wave only.

4.5 Estimation Results

4.5.1 MNL and Mixed Logit

The presence of switching costs is tested in four specifications. First, multinominal logit is estimated assuming that switching costs are the same across networks (specification I in Table (4.6)). The utility of the outside option is normalized to zero. Since only differences in utility matter, all estimates are interpreted as a differential effect of the utilities of mobile operators, compared to fixed line subscription. All consumer characteristics are significant and have plausible signs. The probability of starting usage of mobiles increases for employed individuals and is higher for males. Moreover, consumers above 30 years old are less willing to start using mobile services than very young consumers. This probability decreases dramatically for consumers above 60 years. There are some differences in the estimates across networks that should capture part of consumer heterogeneity. Furthermore, the value of mobile telephony is rising over time, as represented by dummies for the second and third wave. The estimates of time dummies are interpreted relative to the value of mobile telephony in the first wave. Simple logit estimates indicate presence of significant switching costs between mobile services. As discussed in the subsection on the estimation methodology, simple logit ignores the presence of persistent heterogeneity which leads to overestimated switching costs.

In the second specification, switching costs are assumed to differ according to the network from which consumers switch (specification II in Table 4.6). As already argued, such differences may be explained by varying contractual and psychological costs. Indeed, there are significant differences in switching costs according to multinominal logit estimates. The consumers of Orange have the highest switching costs, the consumers of Vodafone the lowest. The likelihood ratio test can reject the hypothesis that switching costs do not differ across network operators. The test statistics is equal to $\chi^2 = -2ln\frac{L_0}{L_1} = 28$, while the critical value for 3 degrees of freedom is equal to

$\chi^2(0.01, 3) = 11.34$.

Third, mixed logit is estimated, in which consumers are assumed to have switching costs, along with persistent unobserved brand preferences. Thus, the utility specification (4.1) includes non-zero ξ_{ij}. This specification implies temporal and intertemporal dependence of choices. There is significant variation in individual preferences for network operators given by the standard deviations for firm dummies (specification III and IV in Table 4.6). The overall fit improves for mixed logit specification. The likelihood ratio test can reject the hypothesis that there is not persistent consumer heterogeneity. The test statistics is equal to $\chi^2 = 26$ which is greater than the critical value for 4 degrees of freedom $\chi^2(0.01, 4) = 13.28$ (specification II against III in Table 4.6). The estimates of switching costs decrease which indicates that their magnitude was overestimated in simple logit. For comparison, in the final estimation consumers are assumed to have no switching costs at all (specification IV in Table 4.6). The worse fit suggests that true state dependence is present, as estimated in specification III in Table 4.6.

4.5.2 Logistic Regression

Next, the determinants of decision whether to switch network operator are estimated. For this purpose, I use the group of consumers which provided information about the mobile operator of their choice both in the second and third wave. The estimation of determinants for switching between first and second wave is not possible due to missing data, but there should be no significant differences in results. The estimation results of the logistic regression (4.4) are presented in Table (4.8). Relative to consumers of BT Cellnet, the subscribers to Vodafone are more likely to switch and the subscribers to Orange are more likely. This result is in accordance with the estimates of switching costs. The estimates of consumer characteristics have plausible interpretation. Older consumers are less willing to switch (Age) which is consistent with findings in the Oftel's surveys. Consumers who tend to spend more time on reading books (Leisurg) and on housework (Housewk) are more willing to switch, but also consumers who spend more time watching live sports (Leisurb) are more likely to change operator. Finally, consumers who declared that they replaced the usage of fixed line services by the usage of mobile services (Mpuse) are also more likely to switch networks. This is consistent with Oftel's finding that heavier users tend to switch more. Table (4.8) lists some statistical tests of the model, such as the AIC, Schwartz Bayesian Criterion and Likelihood-Ratio test. These tests do not allow to reject the null hypothesis that none of the explanatory variables is related to changes in the probability of switching.

4.6 Conclusion

Numerous studies suggest presence of switching costs in mobile telephony. This paper estimates the magnitude of switching costs in mobile industry using multinominal logit and mixed logit for panel data on British households in years 1999-2001. To the best of my knowledge, this is the first empirical analysis addressing the issue of switching costs between network operators in the mobile telecommunications industry.

According to the estimation results, the time-dependence of choices of network operators is due to both switching costs and persistent tastes. Switching costs differ significantly across network operators. When multinominal logit is estimated, switching costs are significant, but overestimated due to ignorance of unobservable tastes. Thus, this study indicates the importance of unobservable heterogeneity of tastes in the estimation of switching costs. Apart from unobserved heterogeneity, the choices of network operators are explained by consumer characteristics, such as gender, age and the employment status The consumers of Orange have the highest switching costs and consumers of Vodafone the lowest. Furthermore, in the logistic regression, the probability of switching depends on consumer characteristics, such as age, usage intensity and ways of spending leisure time. This is consistent with findings in consumer surveys conducted by the British regulator Oftel.

4.7 Appendix

Table 4.1: Switching between waves 1/2 and 2/3

Wave 1/2	Cellnet	Orange	Vodafone	One2One	Fixed	Total	Oftel
Cellnet	52 61.9%	8 9.5%	8 9.5%	9 10.7%	7 8.3%	84 32.2%	34.00%
Orange	3 6.3%	34 72.3%	0 0.00%	5 10.6%	5 10.6%	47 18.0%	15.00%
Vodafone	18 17.4%	9 8.7%	65 63.1%	3 2.9%	8 7.7%	103 39.5%	38.00%
One2One	3 11.1%	0 0.00%	5 18.5%	17 62.9%	2 7.4%	27 10.3%	13.00%
Total	76 29.1%	51 19.5%	78 29.8%	34 13.0%	22 8.4%	239 100.00%	
Fixed	99 12.8%	67 8.7%	81 10.5%	45 5.8%	480 62.2%	772 100.00%	
Wave 2/3	Cellnet	Orange	Vodafone	One2One	Fixed	Total	Oftel
Cellnet	148 75.5%	9 4.5%	19 9.7%	13 6.6%	7 3.6%	196 32.98%	32.00%
Orange	9 6.1%	126 85.1%	6 4.0%	3 2.0%	4 2.7%	148 25.13%	22.00%
Vodafone	23 13.7%	15 9.0%	112 67.0%	13 7.8%	4 2.4%	167 28.45%	27.00%
One2One	10 11.9%	7 8.3%	3 3.6%	57 67.8%	7 8.3%	84 13.44%	19.00%
Total	190 32.0%	157 26.4%	140 23.5%	86 14.4%	22 3.7%	595 100.00%	
Fixed	61 10.9%	83 14.9%	53 9.5%	41 7.3%	320 57.3%	558 100.00%	

Table 4.2: Consumer choices over three waves

Wave 1	Wave 2/3	Fixed	Cellnet	Orange	Vodafone	O2O	missing	Total
Fixed	Fixed	231	39	62	37	28	83	480
	Cellnet	5	61	3	4	4	22	99
	Orange	2	2	50	2	1	9	66
	Vodafone	4	9	4	30	6	28	81
	One2One	3	3	2	0	20	17	45
	missing	0	0	0	0	0	507	507
	Total	245	114	121	74	59	666	1278
Cellnet	Fixed	2	1	0	0	1	3	7
	Cellnet	1	33	1	4	3	10	52
	Orange	1	1	3	1	0	2	8
	Vodafone	0	2	1	3	0	2	8
	One2One	1	2	0	0	3	3	9
	missing	0	0	0	0	0	60	60
	Total	5	39	5	8	7	80	144
Orange	Fixed	2	1	0	0	0	2	3
	Cellnet	0	1	0	0	1	1	3
	Orange	0	1	17	2	1	13	34
	Vodafone	0	0	0	0	0	0	0
	One2One	1	0	1	0	1	2	5
	missing	0	0	0	0	0	39	39
	Total	3	3	18	2	3	57	86
Vodafone	Fixed	2	0	1	2	0	3	8
	Cellnet	0	10	0	3	1	4	18
	Orange	1	0	7	0	0	1	9
	Vodafone	0	4	6	34	4	17	65
	One2One	0	0	0	0	2	1	3
	missing	0	0	0	0	0	62	62
	Total	3	14	14	39	7	88	165
O2O	Fixed	0	1	0	0	0	1	1
	Cellnet	0	1	0	0	1	1	3
	Orange	0	0	0	0	0	0	0
	Vodafone	0	0	0	3	0	2	5
	One2One	0	0	0	1	10	6	17
	missing	0	0	0	0	0	24	24
	Total	0	2	0	4	11	34	51
missing	Fixed	83	19	20	14	12	0	148
	Cellnet	1	42	5	8	3	0	59
	Orange	0	5	49	1	1	0	56
	Vodafone	0	8	4	41	3	0	56
	One2One	2	5	4	2	21	0	34
	Total	86	79	82	66	40	0	353

Table 4.3: Call success rate survey

	Held calls	Set-ups	Connect& complete	Held calls	Set-ups	Connect& complete
	Cellnet			One2One		
East Anglia	95.2%	95.9%	99.3%	98.8%	99.4%	99.4%
London	96.6%	98.4%	98.2%	96.0%	97.3%	98.7%
Midlands	97.4%	98.6%	98.8%	97.4%	98.6%	98.8%
Northern England	97.2%	98.5%	98.7%	97.0%	98.5%	98.5%
Northern Ireland	93.8%	96.6%	97.2%			
Scotland	95.4%	98.0%	97.4%	88.0%	91.6%	96.1%
South East Engl.	96.4%	98.3%	98.1%	96.6%	98.4%	98.2%
South West Engl.	96.2%	97.7%	98.5%	96.8%	98.6%	98.2%
Wales	94.8%	96.4%	98.4%	84.7%	88.3%	95.8%
National	96.5%	98.1%	98.3%	95.6%	97.3%	98.3%
	Orange			Vodafone		
East Anglia	98.8%	99.3%	99.5%	98.9%	99.4%	99.5%
London	97.4%	99.0%	98.4%	96.0%	97.2%	98.8%
Midlands	97.6%	98.4%	99.3%	96.8%	98.2%	98.6%
Northern England	98.6%	99.2%	99.5%	96.5%	98.3%	98.2%
Northern Ireland	97.2%	98.2%	99.1%	95.8%	97.0%	98.8%
Scotland	96.1%	96.9%	99.2%	96.3%	98.2%	98.1%
South East Engl.	97.5%	98.4%	99.1%	97.3%	98.6%	98.7%
South West Engl.	97.9%	99.1%	98.8%	97.2%	98.5%	98.7%
Wales	96.7%	97.7%	98.9%	90.4%	93.8%	96.3%
National	97.7%	98.6%	99.1%	96.4%	97.9%	98.4%

Source: Mobile network operators' call success rate survey October 1999 – March 2000, Published May 2000 by Oftel

Table 4.4: The cost of using mobile services in the UK per annum: representative mobile packages for two different calling patterns

Operator	Package	Fix.	Nat.	Mob.	Int.	SMS	Disc.	Hand	Sum
Basket 1									
Orange	Pre/Just Talk	0.0	12.8	4.5	0.2	2.8	0.0	60.0	80
One2One	Pre/Up2You Std	0.0	15.5	3.4	1.4	0.7	0.0	60.0	81
Cellnet	Pre/Pay & Go	0.0	18.3	4.3	1.4	3.1	0.0	60.0	87
Vodafone	Pre/Pay As U Talk	0.0	18.3	4.9	0.6	8.3	0.0	60.0	92
Basket 2									
Orange	Pre/Just Talk	0.0	40.6	16.9	1.7	3.6	0.0	60.0	123
One2One	Pre/Up2You Std	0.0	48.7	12.7	13.5	2.4	0.0	60.0	137
Cellnet	Pre/Pay & Go	0.0	58.0	16.2	13.5	4.8	0.0	60.0	152
Vodafone	Pre/Pay As U Talk	0.0	58.0	18.6	6.2	10.4	0.0	60.0	153

Source: "International benchmarking study of mobile services and dial-up PSTN Internet access", Oftel, December 2000

Table 4.5: Descriptive statistics of variables used in simple logit and mixed logit

Variable						
Wave 3	Description	N	Mean	Std	Min	Max
work	employment dummy	1725	0.56	0.49	0	1
sex	sex dummy(female=1)	1725	0.54	0.50	0	1
age	age	1725	44.60	17.96	16	93
age> 30	dummy for 60 >age> 30	1725	0.53	0.50	0	1
age> 60	dummy for age> 60	1725	0.21	0.41	0	1
Wave 2						
work	employment dummy	1033	0.61	0.49	0	1
sex	sex dummy(female=1)	1033	0.56	0.49	0	1
age	age	1033	46.00	16.61	16	90
age> 30	dummy for 60 >age> 30	1033	0.59	0.49	0	1
age> 60	dummy for age> 60	1033	0.21	0.41	0	1
Wave 1						
work	employment dummy	1153	0.59	0.49	0	1
sex	sex dummy(female=1)	1153	0.56	0.49	0	1
age	age	1153	47.22	16.59	16	87
age> 30	dummy for 60 >age> 30	1153	0.60	0.49	0	1
age> 60	dummy for age> 60	1153	0.23	0.42	0	1

Table 4.6: Simple logit and mixed logit for panel data

		I		II		III		IV	
	Variables	Est.	t	Est.	t	Est.	t	Est.	t
r_j	Cellnet	-2.183	-12.93	-2.152	-12.81	-2.595	-11.35	-4.690	-11.12
	Orange	-2.298	-13.46	-2.360	-13.22	-2.458	-13.28	-4.678	-12.02
	Vodafone	-2.041	-12.19	-2.007	-12.15	-2.529	-9.46	-4.870	-10.34
	One2One	-2.512	-12.22	-2.559	-12.14	-2.841	-10.64	-5.421	-10.39
std	Cellnet					1.140	5.99	3.257	13.19
	Orange					0.401	1.82	2.815	12.87
	Vodafone					1.243	5.02	3.528	11.62
	One2One					0.766	2.60	3.104	10.38
time	wave 2	0.865	10.15	0.877	10.30	1.005	10.41	2.117	14.98
	wave 3	1.526	15.93	1.520	15.84	1.756	14.84	3.695	19.85
s costs	mob2mob	-2.647	-28.79						
	Cellnet			-2.435	-16.06	-2.145	-10.14		
	Orange			-3.366	-16.62	-3.374	-11.39		
	Vodafone			-2.232	-14.39	-1.777	-6.84		
	One2One			-2.980	-13.37	-2.899	-10.98		
Cell.	age> 30	-0.241	-1.70	-0.233	-1.65	-0.208	-1.27	-0.151	-0.51
	age> 60	-0.985	-4.77	-0.990	-4.83	-1.108	-4.64	-1.837	-4.52
	sex	-0.355	-3.03	-0.359	-3.09	-0.421	-3.06	-0.761	-3.09
	employed	0.670	4.78	0.665	4.81	0.732	4.58	1.004	3.77
Orange	age> 30	-0.371	-2.63	-0.388	-2.64	-0.420	-2.79	-0.698	-2.65
	age> 60	-1.129	-5.47	-1.135	-5.34	-1.189	-5.48	-2.105	-5.50
	sex	-0.307	-2.54	-0.313	-2.52	-0.320	-2.53	-0.514	-2.19
	employed	0.693	4.77	0.680	4.46	0.685	4.42	1.142	4.54
Vodaf.	age> 30	-0.359	-2.54	-0.339	-2.43	-0.326	-1.96	-0.353	-1.18
	age> 60	-1.386	-6.14	-1.369	-6.10	-1.574	-6.04	-2.760	-6.07
	sex	-0.571	-4.66	-0.565	-4.67	-0.655	-4.46	-1.177	-4.27
	employed	0.640	4.41	0.661	4.63	0.805	4.59	1.371	4.72
O2O	age> 30	-0.372	-2.14	-0.370	-2.08	-0.435	-2.30	-0.812	-2.58
	age> 60	-1.696	-5.96	-1.673	-5.85	-1.795	-5.84	-3.063	-6.11
	sex	-0.229	-1.48	-0.222	-1.42	-0.226	-1.37	-0.346	-1.17
	employed	0.328	1.90	0.320	1.82	0.316	1.69	0.432	1.40
LL	N of obs.	3908		3908		3908		3908	
	N of cases	19540		19540		19540		19540	
	Log Lik.	-3980		-3966		-3953		-4110	

Table 4.7: Descriptive statistics of variables used in switching regression

Variable	Description	N	Mean	STD	Min	Max	Corr.
Mobbill	Quarterly mobile bill	672	87.70	71.58	12.0	450.0	1.00
Mpcalln	Mobile - average calls per week	672	3.53	1.64	1.0	6.0	0.51
Cellnet	Cellent dummy	672	0.32	0.47	0.0	1.0	-0.05
Orange	Orange dummy	672	0.20	0.40	0.0	1.0	0.05
Vodafone	Vodafone dummy	672	0.32	0.47	0.0	1.0	-0.00
One2One	One2One dummy	672	0.12	0.33	0.0	1.0	0.02
Age	Age	668	40.49	12.85	16.0	77.0	-0.14
Leisurb	Leisure: watch live sport	672	4.51	1.11	1.0	6.0	-0.06
Leisurd	Leisure: meal in restaurants	672	2.84	0.90	1.0	6.0	-0.21
Leisurh	Leisure: drink in pub-club	476	2.95	1.25	1.0	5.0	-0.14
Leisurg	Leisure: read books	672	2.59	1.64	1.0	6.0	0.06
locrang	Non-local friends&relatives	476	3.15	1.61	0.0	5.0	0.08
Housewk	Time spent housework in week	650	8.49	8.36	0.0	70.0	-0.14
Rushd	Rush - tasks around home	476	2.86	1.14	1.0	8.0	0.09
Rushe	Rush - shop for essentials	476	3.35	1.10	1.0	8.0	-0.09
Mpwhy2	Mobile - reason useful for work	536	1.60	0.48	1.0	2.0	-0.26
Mpwhy7	Mobile - reason personal safety	476	1.36	0.48	1.0	2.0	0.32
Mpwhy1st	Mobile - reason 1st important	476	2.29	1.26	1.0	5.0	-0.18
Mpuse	Mobile - replace phone use	672	2.70	0.60	1.0	8.0	-0.27
Mptype	Mobile - payment type	476	2.05	0.57	2.0	9.0	-0.08
Empstat	Current employment situation	672	1.77	1.62	1.0	9.0	-0.11
Employed	Employment dummy	672	0.76	0.42	0.0	1.0	0.16
Retired	Retirement dummy	672	0.09	0.28	0.0	1.0	-0.11
Nowork	Unemployment dummy	672	0.08	0.28	0.0	1.0	-0.14
Student	Student dummy	672	0.05	0.22	0.0	1.0	0.03

Table 4.8: Analysis of Maximum Likelihood Estimates

	Model I			Model II		
Variables	Estimate	Wald χ^2	sign.	Estimate	Wald χ^2	sign.
Intercept	1.37	0.97	0.32	-0.38	0.23	0.62
Class 2	0.004	0.00	0.99			
Class 3	-0.33	0.36	0.54			
Class 4	0.23	0.14	0.70			
Class 5	-0.45	0.47	0.49			
Class 6	-0.17	0.08	0.76			
Orange	-0.54	2.66	0.10	-0.63	4.27	0.03
Vodafone	0.53	3.84	0.04	0.48	4.22	0.03
One2One	0.30	0.77	0.37			
Age	-0.02	4.01	0.04	-0.01	5.74	0.01
Leisurb	-0.19	3.23	0.07	-0.18	3.08	0.07
Leisurd	0.06	0.22	0.63			
Leisurh	-0.10	1.08	0.29			
Leisurg	-0.21	7.62	0.00	-0.18	6.59	0.01
Locrang	0.006	0.00	0.93			
Housewk	0.02	3.83	0.05	0.02	4.55	0.03
Rushd	-0.03	0.12	0.72			
Rushe	-0.06	0.32	0.57			
Mpwhy2	-0.47	2.74	0.09			
Mpwhy7	-0.35	1.49	0.22			
Mpwhy1st	0.04	0.23	0.62			
Mpuse	0.32	1.87	0.17	0.30	1.90	0.16
Mptype	-0.04	0.07	0.78			
Retired	0.48	1.86	0.17	0.41	1.60	0.20
Nowork	0.26	0.27	0.59			
Student	-0.11	0.06	0.79			
Model Fit	Intercept	Covariates		Intercept	Covariates	
N used	550			550		
AIC	581.599	585.067		581.599	559.752	
SC	585.909	697.125		585.909	598.542	
-2 Log L	579.599	533.067		579.599	541.752	
L-Ratio	46.53	0.0056		37.84	0.0001	
Score	44.47	0.0096		36.46	0.0001	
Wald	40.19	0.0278		33.67	0.0001	

Chapter 5

The Competitiveness of Mobile Telephony across the EU

5.1 Introduction

Traditionally, the telecommunications industry was perceived as a public monopoly and was regulated by politically influenced national authorities. More recently, the development of the pan-European liberalized telecommunications industry has become an important component of European economic integration. The first steps towards the constitution of a common regulatory framework for telecommunications services in the European Union can be traced back to 1984.[1] The main aspects of regulation were the development of standards, common research and development programs for the least developed regions. The second phase was initiated in 1987, when the European Commission (EC) published the Green Paper on the development of the common market for telecommunications services and equipment.[2] It was followed by many successive Resolutions regarding the telecommunications industry. In April 1994, for example, the Commission published the Green Paper on mobile and personal communications

[1] For a detailed report on the regulation of telecommunications industry in the European Union see: European Commission (1999) ”Status Report on European Union Electronic Communications Policy”.

[2] Source: European Commission (1987) ”Towards a dynamic European economy: Green Paper on the development of the common market for telecommunications services and equipment”.

which addressed the need for a common regulatory framework for mobile services.[3] This Green Paper points out the particular role of mobile services for the future of the telecommunications industry and the prospective benefits for society at large. It also sets out the main goals of telecommunications policy, in particular, the creation of a mass market for personal communications services and the foundation of pan-European networks and services.

In March 2002, the EC adopted a new regulatory framework for electronic communications which responds to the changes in the telecommunications industry after the liberalization on January 1, 1998. It should have been implemented in all Member States by July 2003, but eight Member States failed to meet this deadline and in October 2003 the EC opened infringement proceedings against those countries.[4] The new framework assumes that the national regulators are able to correctly assess the level of competition and should therefore apply the regulatory obligations only when competition is not in effect.[5]

The EC is responsible for providing a common European regulatory framework for the telecommunications industry and for monitoring its implementation. All Member States must establish independent national regulatory authorities (NRAs) responsible for the implementation of regulations within the country's territory. The main tasks of the NRAs, as defined by the Commission Directives, are consumers protection and the establishment of an innovative, competitive, and sustainable telecommunications industry.[6] The competencies of NRAs, the objectives and the intensity of regulation vary across countries. Governments and regulators approach many regulatory issues differently, for instance, the licensing policy in the mobile industry. This might be one

[3]Source: European Commission (1994) "Towards a personal communications environment: Green Paper on a common approach to mobile and personal communications in the European Union".

[4]Source: European Commission (2004) "Six Member States face Court action for failing to put in place new rules on electronic communications".

[5]Source: European Commission (2002) "Eighth Report on the Implementation of the Telecommunications Regulatory Package".

[6]Source: European Commission (2002) "Eighth Report on the Implementation of the Telecommunications Regulatory Package".

of the reasons why the market structure, growth rates and prices differ by country. In addition, there could be some other non-regulatory country-specific factors that influence the diffusion and prices in the telecommunications industry. For instance, the diffusion of mobile services might depend on the cultural background of the society, wealth status, or geographical characteristics of the country.

According to the new regulatory framework for electronic communications, assessment of industry competition is the basis for regulatory intervention. For instance, the EC assigned the consultancy firm Teligen to conduct analysis of competition in telecommunications industry across the EU countries. Teligen uses data on the market structure, prices and regulation to develop the "Index of Competitive Development", which quantifies the degree of competition in key telecommunications services.[7] The index is constructed by scoring and weighting the variables identified as measures of competition. Hence, this index represents only an intuitive evaluation of competition and can lead to misleading conclusions. In the present paper, I use a simple theoretical framework to analyze the impact of regulatory policy and country-specific factors on the development and competitiveness of mobile telecommunications industry across the European Union.

In order to assess the impact of regulation on demand and prices of mobile services, I estimate a reduced form model using data for the EU countries from 1998 to 2002. I consider a set of regulatory variables, which are perceived as pro-competitive tools, such as the introduction of number portability, regulation of interconnection charges and presence of airtime resellers. Number portability reduces consumer switching costs and should decrease prices (-). The regulation of interconnection charges should decrease marginal costs of providing mobile services in the industry and therefore may lower prices (-). The presence of airtime resellers might increase competition and cause prices to fall (-). Moreover, liberalization of fixed-line telephony caused more intense regulation of fixed telephony or communications services in general, which surely had

[7] Source: Teligen (2000) "Study on Market Entry Issues In EU telecommunications Markets After 1 st January 1998: A Report for the European Commission"

an impact on competition in the mobile industry (-).

Indeed, the estimation results suggest that the regulatory policy significantly influences the level of prices and the demand for mobile services. In particular, the liberalization of fixed-line telephones has a significant negative impact on prices and a positive impact on the demand for mobile services. Similarly, the implementation of number portability in the mobile industry has a negative impact on prices. Furthermore, regulation of interconnection charges through the designation of mobile operators with significant market power increases the demand for mobile telephony but the estimate remains insignificant on the supply side. The presence of airtime resellers, which in the opinion of regulators should decrease prices, is in fact, insignificant. Moreover, due to technological innovation, the mobile industry has enjoyed a substantial annual increase in demand.

Afterwards, I use significant explanatory variables to estimate a structural model. In this way some important information about the industry could be retrieved, in particular, the estimates of price elasticity and average market conduct. Eventually, the Member States could be compared in respect to the level of competition in mobile telephony, which is a valuable information for the regulatory authorities.

There is a large body of studies conducted by different consultancy firms on behalf of the EC. These consultants assess the progress in the implementation of the telecommunications regulatory framework across Member States. However, contrary to this study, most of the publicly available reports provide descriptive analysis of the industry. A multivariate econometric analysis is required to justify and approximate the influence of particular regulatory and non-regulatory factors. To the best of my knowledge, apart from Gruber and Verboven (2001), there is no other econometric study that addresses the impact of regulation on the diffusion of mobile telecommunications services across the EU. Their study indicates the importance of government regulation and technological progress for the development of the industry. In particular, the increase in capacity and quality of services, through the transition from analog to digital technology, results in an increase in the subscriber base. Moreover, competition, defined as at least two competitors on the market, contributed to diffusion of mobile services. However, Gruber and Verboven (2001) estimate a logistic diffusion model using panel data up to 1997 and the question of the importance of further regulation remains unanswered. Moreover, they do not use price data to jointly analyze the demand and supply sides. Such an analysis is conducted by Parker and Röller (1997) for the mobile telecommunications industry in the U.S. They estimate a simple static structural model of competition to examine the determinants of market conduct. This theoretical framework was widely applied in the new empirical industrial organization literature (NEIO) (see Bresnahan (1989)). However, apart from high demand on data, there are also theoretical disadvantages of such analysis (see Corts (1999)).

In the next section I provide a short introduction of the evolution of the mobile telecommunications industry and its regulation in the European Community. In section 3, I derive the model for the empirical analysis, present the data, provide the estimates of the model. The estimation results are discussed in section 4. The final section provides conclusion.

5.2 Mobile services in the European Union

5.2.1 Development of the Mobile Industry

The era of mass mobile telecommunications in the European Union started in the early 1980s with the first generation analog systems, such as Nordic Mobile Telephone (NMT), British Extended Total Access Communication System (ETACS) and the German standard (C-450). These systems were primarily designed for the transmission of voice signals. Because of capacity constraints, incompatibility, low quality and security, the analog systems have been phased out. The licenses for providing analog mobile services were granted to state-owned, fixed-line monopolies, with the exception of France, the United Kingdom and Sweden, where duopolies were created. After the invention of second generation technology (2G), European countries decided to introduce common technology platforms GSM-900 and later DCS-1800, to allow for pan-European roaming. This time the licenses were not exclusively granted to the incumbent operators. Licensing policies varied by countries, allowed for a different number of operators and simultaneous or sequential market entries. The second-generation technologies should be followed by third-generation systems (3G), which combine the mobile voice communications functions with high capacity data transfer and mobile access to the Internet. The licenses for UMTS technology were first granted in Finland in March 1999 and last in Ireland in June 2002. The extremely high cost of licenses in some countries and the slowdown in the global economy postponed the development of UMTS networks. Thus, the analysis of 2G mobile markets across the EU is a relevant basis for determining the economic and regulatory factors that accelerate the diffusion of UMTS technology.

The implementation of 2G technology was, in fact, extremely successful. Within a very short period of time, mobile phones became a common product with a penetration rate above that of any other telecommunications service. At the end of year 2001, about 73% of EU citizens were users of mobile networks and the value of the mobile telecommunications market was expected to reach approximately 82 billion euros (about 38% of the total revenue in the telecommunications industry)[8]. The establishment of a competitive market structure resulted in lower prices, and greater variety and quality of mobile services. However, penetration rates and price levels differ across Member States. One possible explanation is variation in the regulatory policy, which is the subject of this study.

5.2.2 Regulation of the Mobile Industry

Until 1998 the telecommunications regulatory policy focused mainly on the liberalization of fixed-line telephony. After 1998, foreseeing the future convergence of fixed and

[8]Source: European Commission (2001) "Seventh Report on the Implementation of the Telecommunications Regulatory Package".

mobile telecommunications services, the regulators concentrated on the mobile industry as well. Also, the new regulatory framework for electronic communications is, to a great extent, concerned with the regulation of mobile telephony.

Some tools of the telecommunications regulatory policy could have crucial influence on industry growth and prices. First, NRAs have the ability to designate any operator as having a significant market power (SMP) in the retail or interconnection market. In the retail market, an operator is designated to have an SMP when its subscriber market share exceeds 25%.[9] In the year 2002, in thirteen EU countries, at least two mobile operators were designated to have an SMP status. In Germany and Austria, no operator was designated, even though this criterion was fulfilled. German NRA explained this decision by sufficient demand power, while the Austrian regulator did not provide any explanation. The operators designated with an SMP in the retail market are under special supervision. In particular, the regulators enforce the obligation of charging non-discriminatory, transparent, and cost-oriented retail prices. The other obligations imposed refer to cost accounting and network access.[10] In the interconnection market, an operator is designated to have an SMP when its market share exceeds 25% in total revenue from call termination on mobile and fixed networks, including on-net calls.[11] In a few Member States, some operators were designated even though this criterion was not fulfilled. In these cases regulators had made use of some other criteria provided in the Interconnection Directive. The operators designated with an SMP in the interconnection market must adopt the cost orientation principle for call termination charges.[12] The access charges can represent an important component of

[9]Source: European Commission (1997) "Directive 97/33/EC of the European Parliament and of the Council of June 30, 1997, on interconnection in Telecommunications with regard to ensuring universal service and interoperability through application of the principles of Open Network Provision (ONP)".

[10]Source: European Commission (2002) "Eighth Report on the Implementation of the Telecommunications Regulatory Package".

[11]Source: European Commission (1999) "Explanatory Note on Determination of Organisations with SMP for implementation of the ONP Directives".

[12]Source: European Commission (2002) "Eighth Report on the Implementation of the Telecommunications Regulatory Package".

the marginal cost of providing mobile services. Thus, the cross-country variation in prices could be partially explained by differences in the regulation in terms of the SMP designations.

The industrial organization literature suggests that the presence of switching costs increases long-term equilibrium prices.[13] Thus, high prices in mobile telephony may be explained by the existence of consumer switching costs. Two of the key regulatory tools reducing switching costs are carrier selection (CS) and carrier pre-selection (CPS), which allow consumers to access other networks without being directly connected to them. CS and CPS for mobile services were not mandated in the previous regulatory framework for electronic communications. Hence, in 2002 they were in place in only a few Member States and mostly for international calls (CS and CPS exist in Denmark, Spain and Finland; CS only in Portugal and the UK). In fixed telephony the CS and CPS were already implemented in all EU countries in year 2002. The other key pro-competitive tool that reduces consumer switching costs is the portability of numbers. In mobile telephony, similar to CS and CPS, it was not mandated in the former regulatory framework. However, in year 2002, the mobile number portability (MNP) was already implemented in nine Member States. In the case of fixed telephony, it was available in all Member States in the year 2002.[14]

The licensing regime (i.e., the number of active network operators and the timing of entries) could significantly explain the variation in prices. Moreover, the NRAs in some countries enforce the presence of independent service providers, which buy airtime from network operators and resell it to end users under their own brand names. The presence of airtime resellers is perceived by the regulators as a necessary component of a competitive environment in mobile telephony. The mobile industry is limited by the scarcity of available spectrum. Thus, the airtime resellers can provide some additional services and extend product variety. Furthermore, the presence of independent service

[13]See Klemperer (1995) for an excellent survey on competition in markets with switching costs.

[14]Source: European Commission (2002) "Eighth Report on the Implementation of the Telecommunications Regulatory Package".

providers may exercise competitive pressure and cause prices to fall. However, the resellers' prices usually mimic the prices of network operators, whose airtime they resell.

Apart from the factors mentioned above, some other regulatory issues may have an impact on the prices of mobile services, such as interconnection regime, competencies of NRAs, etc. Unfortunately, the impact of these factors is very difficult to measure and is not considered in this study.

5.2.3 Prices of Mobile Services

Mobile operators provide a wide range of services and apply price discriminating strategies. Some simplifications are necessary to conduct an empirical analysis and create a single price index for mobile services.

It is common practice to classify consumers into two main segments, business and residential users, with respect to their patterns of use (high and low use). Residential consumers pay lower monthly rental fees and higher calling charges, while business consumers pay higher rental fees and lower calling charges. Operators usually target each segment with a few different tariffs. Each tariff may set different charges for particular services. Typical tariff components are connection charge, monthly rental fees, call charges differentiated according to on-net and off-net destination or peak and off-peak timing. Moreover, firms differentiate tariffs according to the billing of calls, SMS, WAP, and mailbox charges, as well as discounts, such as free minutes or special prices for selected phone numbers. Prices tend to change very often, for example, some tariffs are cancelled or replaced by others or new services are introduced, which makes the analysis of price evolution hard. Although national statistical offices spend significant resources constructing price indices for mobile services, using these indices for price comparisons between countries is inadequate because of the different definitions of monthly use baskets.

To make this analysis reliable, prices must be comparable across countries and over time. On behalf of the OECD the consultancy agency Teligen applies a representative basket methodology to analyze quarterly price developments of basic telecommunications services. However, this data is not available publicly and Teligen's definition of baskets alters over time in order to account for changes in service use. Thus, any comparison through time of the prices provided for the OECD is impossible. Therefore, publicly available reports prepared by Teligen for the EC are used to construct my own price indices. These reports contain detailed annual price information on basic telecommunications services. In defining the basket, I followed the guidelines provided by the OECD.[15] Only the most important pricing elements are used in the calculation, such as connection charges, monthly rental charges, on-net, and off-net, peak, and off-peak call charges with appropriate weights. Based on the incumbents' tariffs for representative residential users, I create price indices for mobile services covering years from 1998 to 2002.[16]

Consumers are assumed to make 365 calls a year of a 3 minutes duration. Out of these, 80% are national calls to fixed numbers and 20% are to mobile numbers within the same network. In total, 30% of all calls are made during the peak time and 70% during the off-peak time. The monthly cost of the service consists of the total annual cost of calls plus one-third of the network connection fee divided by twelve, plus the monthly rental charge. The indices include VAT and are listed in $US PPP. The measurement of prices in $US PPP makes them comparable across the EU countries and over time. The most critical assumption, made in the definition of price indices, is that the incumbents' tariffs are representative of the whole industry, which I make because of the lack of other comparable price data. However, the OECD and the EC make the same assumption in their comparisons of prices across countries.

[15]Source: Teligen (2000) "OECD Telecommunications Basket Definitions".

[16]The tariffs are from January of each year, with the exception of the years 2001 and 2002, for which the tariff is taken from December of the previous year. It is reasonable to assume that it do not differ much from January's tariff.

5.2.4 Mode of Competition

In general, retail market for mobile services may be divided into two segments: residential and business users. According to a survey conducted by the EOS Gallup Europe on behalf of the EC, in year 1999, 100% of small enterprizes across the EU countries were equipped with at least one mobile phone.[17] Therefore, observed growth in mobile subscriptions, in the time period analyzed in this study, may be fully attributed to residential users.[18]

Individual consumers decide about the network to which they want to subscribe after they compare tariffs offered by different operators. They select a package which best fits to their calling behavior. Basically, three decision stages may be distinguished: subscription to network operator, choice of tariff and usage pattern, that is, what are the usage preferences for particular services available within the package. Moreover, decision about network subscription is determined by attractiveness of the handset, which usually is part of the package. The more attractive is the handset, the more valuable is particular tariff and network. Hence, firms provide handset subsidies, and often distribute handsets for free. Afterwards, firms try to recoup their initial investment in consumers by setting higher prices of mobile services. In the present study, I assume that the full cost of handset is included in the cost of service usage. However, in fact, the regulation of competition in handset subsidies differs by country. In the case of some countries it is prohibited, for instance, in Finland. Unfortunately, a precise cross-country data about the regulation and competition in handset subsidies is not available.

In deriving the model, I make an assumption, which corresponds to Parker and Röller (1997) as applied to the US mobile industry, that firms compete in quantities. The common reasoning is such: due to spectrum scarcity firms strategically set the

[17]Source: European Commission (1999) "The Situation of Telecommunications Services in the Regions of the European Union"

[18]A dramatic change in the number of firms or in the number of mobile subscribers within one company is rather unlikely.

amount of subscriptions to sell. Indeed, this was the case for analog networks. Moreover, according to Kreps and Scheinkman (1983), under certain conditions, the capacity constrained price game yields the same results as the Cournot quantity game. Thus, one could also view the competition in the mobile industry as a game, in which firms strategically install capacity and then compete in prices. First, because the scarcity of spectrum causes capacity restrictions, and second, because price competition may in fact be more accurate for this industry.[19]

Furthermore, I assume that firms use static strategies. However, if firms set prices (quantities) dynamically, that is to optimize long-term profits, the estimates of market power in static models may be seriously misleading, as Corts (1999). Accordingly, in the first part of this study, I use a reduced form to estimate determinants of cross-country and time variation in equilibrium prices and demands. In the second part, I estimate a structural model and attempt to compare the level of competitiveness across the EU countries.

5.3 Empirical analysis

5.3.1 The Data

On behalf of the EC, data have been collected to evaluate the progress in the telecommunications reforms across the European Union. The EC reports on the implementation of telecommunications regulatory package and the International Telecommunications Union (ITU) database are the main sources of data used in this analysis. The price indices described in the previous subsection are developed using reports prepared for the EC by Teligen.

Because of very similar social, economic and regulatory environment in the European Community, some of the variables suggested by previous studies of mobile

[19] In Germany, for instance, the GSM networks were about to reach their capacity limits and were granted additional DCS licenses.

telephony worldwide were not considered in this analysis at all. The variables such as the independence of the NRAs are constant in the country and time dimension.[20] Some other variables are very difficult to quantify to make the countries comparable with each other, such as the interconnection regime, for instance. Furthermore, in the time period considered many regulatory tools had already been implemented, such as the incumbents' privatization, or are still awaiting implementation, such as the carrier selection and pre-selection.

The variables used in the study can be divided into two groups: regulatory variables and non-regulatory country-specific, socioeconomic variables. On the demand side I explain mobile subscriptions (Mobile)[21] with country population as a logarithm (Pop), GDP per capita in $US PPP as a logarithm (GDP), and penetration rate of the fixed-line telephony as a logarithm (Fixed). These variables were used in previous studies, for instance in Gruber and Verboven (2001). They find a significant negative impact of fixed-line subscriptions on the diffusion of mobiles across the EU countries. Moreover, countries with higher GDP per capita may experience a higher demand for mobile services.

The mobile industry has been steadfast in the process of a rapid technological innovation. I account for this using a common time trend variable (Time). It can be interpreted as a constant upgrade in the quality of services, the rising range of available services, as well as the enhanced performance and decreasing prices of mobile handsets.[22] Gruber and Verboven (2001) found that the change from analog to digital technology had a significant impact on the diffusion of mobiles. However, in the time period I analyze, the change was already made and the only way to account for the technological switch is through a variable representing the time passed since the start-up of digital networks. The difference between the time trend and the timing of

[20] According to the EC reports on the implementation of telecommunications regulatory package.

[21] The mobile subscriptions I take from ITU telecommunications database, which does not differentiate between business and residential subscriptions. Pre-paid consumers are included as well.

[22] Mobile telephony is a prime example of an industry with network effects. Because of high collinearity of time trend and past subscriber base, the time trend variable may account for both technological innovation and network effects. However, in the paper I refer to (Time) as technological innovation.

technological change is a different drift for particular countries and both variables are highly correlated, as shown in table 5.4. Therefore, a significant coefficient for only one of the variables can be estimated. Finally, as motivated in the earlier subsection on the regulation of the mobile industry, the presence of airtime resellers could contribute to an increase in demand for mobile services. Because it is relatively difficult to follow the number of resellers and the scale of their activity across the EU countries, I consider their potential impact on the industry by using a dummy variable (Service).

On the supply side, two kinds of explanatory variables are considered to explain the prices of mobile services (Mobbill): exogenous price shifters and the determinants of the marginal cost. As for the price shifters, I consider a set of regulatory variables: a dummy for the introduction of number portability in mobile networks (MNP), a dummy for the allowance of airtime resellers (Service), and a dummy for the liberalization of the fixed telephony market (Libera). All these variables are expected to have a negative impact on prices. Moreover, the pricing equation derived in the next subsection requires an inverse of the number of mobile operators as explanatory variable (1/N).

The other explanatory variables are potential determinants of the marginal cost of providing mobile services. I consider the average hourly labor compensation rate in the industry in $US PPP as the proxy for the cost of labor in the telecommunications industry (Labor), the interest rate on the 10-year government bonds as the proxy for the cost of capital (Bond), and the cost of electricity in $US PPP as the proxy for the marginal cost of call transmissions (Elect). Moreover, I incorporate into the cost function the time trend to account for possible technological innovation on the supply side (Time). Regulation may also lead to lower marginal costs of providing mobile services. I use a dummy for the designation of any mobile operators with an SMP in the interconnection market (SMP).[23] The firms designated with an SMP must set cost-oriented interconnection charges to decrease the marginal costs of the other firms

[23]I do not consider designation with an SMP in the retail market because there is not enough variation. In the whole time period analyzed, almost all NRAs designated at least one mobile operator with an SMP status.

on the market. Moreover, I use the country-specific cost dummies to explain possible differences in the level of marginal costs across countries, for instance, factors such as the differences in the country size or the concentration of population.[24]

An important issue to discuss is whether the regulatory variables in this study might be considered as exogenous at all. The regulator is supposed to adjust the regulation policy to the demand and supply shocks. However, my claim is that such reaction would always be sufficiently delayed to be considered exogenous. At least the regulatory variables considered in this study require respective legislation and the process of their technical implementation is long. On the other hand, lobbying activities could convince the regulator to postpone the introduction of regulatory tools to protect the incumbent operator. The EC imposes an equal regulation policy on all countries and enforces deadlines for its implementation. Moreover, a particular emphasis is put on the independence of the regulators from political influence. Due to the reports of the EC and the ITU, the NRAs in particular countries appear to be sufficiently independent.[25] Hence, the regulatory variables in this study can be considered to be uncorrelated with the unobservable demand and supply shocks.

5.3.2 The Model

The inverse demand function is given by

$$p_{ts} = f(\sum_{i=1}^{N_{ts}} q_{its}, X_{ts}, \epsilon_{ts}), \tag{5.1}$$

where $s = 1, ..., S$ is the country subscript, $t = 1, ..., T$ is the time subscript, N_{ts} is the number of mobile operators in country s at time t, X_{ts} represents observable and ϵ_{ts} unobservable demand shifters. The cost function has the same specification for all

[24]See the Appendix for data sources.

[25]Source: ITU (2002) "Trends in Telecommunication Reform 2002: Effective Regulation - 4th edition".

firms across the EU countries

$$TC_{its} = FC_{its} + VC(q_{its}, W_{ts}, \omega_{ts}), \tag{5.2}$$

where FC_{its} represents firm specific fix costs, changing over time and across countries, VC_{its} is the variable cost depending on the number of network subscriptions and some other country-specific cost drivers W_{ts}. Finally, ω_{ts} stands for unobservable cost shifters. For such demand and cost specifications, a firm's profit function can be expressed as

$$\Pi_{its} = p_{ts}(.)q_{its} - VC(q_{its}, W_{ts}, \omega_{ts}) - FC_{its}, \tag{5.3}$$

which provides the first order conditions in the form

$$\lambda_{its} \frac{\partial p_{ts}(.)}{\partial q_{its}} q_{its} + p_{ts}(.) - MC_{its}(.) = 0, \tag{5.4}$$

where $MC_{its}(.) = \frac{\partial VC_{its}}{\partial q_{its}}$ is the marginal cost function for firm i in country s and $\lambda_{its} = 1 + \sum_{j \neq i}^{N_s} \frac{\partial q_{jts}}{\partial q_{its}}$ is conjectural variation (degree of collusion). The conjectural variation formulation might be interpreted as the firms' expectations about the reaction of the other firms to a change in quantity (see Bresnahan 1989). I sum up FOCs (5.4) over all firms within the industry and divide by the number of firms N_{ts} to get the average industry supply equation in the form

$$\frac{\lambda_{ts}}{N_{ts}} \frac{\partial p_{ts}(.)}{\partial Q_{ts}} Q_{ts} + p_{ts}(.) - \frac{1}{N_{ts}} \sum_{i=1}^{N_{ts}} MC_{its}(.) = 0. \tag{5.5}$$

Three basic cases can be considered: $\lambda_{ts} = 0$ in the perfect competition case, $\lambda_{ts} = 1$ corresponds to Nash equilibrium and $\lambda_{ts} = N_{ts}$ implies joint profit maximization. The existence of any of these equilibria can be tested.

5.3.3 Marginal Cost and Markup

An appropriate definition of marginal cost function is critical to get correct estimates of conjectural variation λ_{ts} in the supply equation. Due to some country-specific factors, both marginal costs and market conduct may differ across the EU countries. The most credible definition of the supply side should include a set of country dummies to explain differences in conduct together with country dummies as components of marginal cost function. However, this already requires an estimation of thirty coefficients for country dummies and intercepts themselves. Given that only five years of data for fifteen countries is available, such model specification is not possible to estimate. Thus, the estimation of the supply side requires additional assumption.

I estimate two different models, in which either conduct or marginal cost is country-specific. In the first case, conjectural variation parameter is country-specific and depends on implemented regulation $\lambda_{ts} = [D_s\eta + R_{ts}\delta]$. Hence, the Member Stats are assumed to have equal technology and conditions for providing mobile services. Apart from variation in the cost factors, there is no difference in marginal cost across the EU countries. Therefore, in fact, I estimate an average marginal cost across the Member States in the time period analyzed. In the second case, I assume country-specific marginal costs and estimate an average market conduct across the EU countries given by $\lambda_{ts} = [\eta + R_{ts}\delta]$. Differences in marginal costs may arise due to differences in country terrain, coverage, law regulation and so on. In both cases firm expectations about the reaction of the other firms to a change in own quantity depend on market regulation in place. Obviously, each assumption introduces bias into estimation results. Therefore, both marginal costs and market conducts could be under or overestimated and neither model can provide correct information. However, these assumptions allow to estimate the supply side. The comparison of estimates in both cases should provide a basis for evaluation of competitiveness across the Member States. In the empirical analysis, I assume a linear (industry average) marginal cost function, which consists of a constant component and other cost determinants. Alternatively, a translog formulation could be used.

5.3.4 The Estimation

I estimate the following demand function

$$log(Q_{ts}) = p_{ts}\alpha + X_{ts}\beta + \epsilon_{ts}, \tag{5.6}$$

where Q_{ts} is the penetration of mobiles, p_{ts} the price index for mobile services, $X_{ts} = [1, Fixed_{ts}, GDP_{ts}, Pop_{ts}, Service_{ts}, Time_t]$ represents a set of exogenous explanatory variables discussed in the previous subsection and ϵ_{ts} is the unobservable error term. For this demand formulation we have $\frac{\partial p_{ts}(.)}{\partial Q_{ts}} = \frac{1}{\alpha Q_{ts}}$.

First, I derive a reduced form model assuming that the collusion parameter is the same across all countries and over time, $\lambda_{ts} = \lambda$. Instead of estimating freely λ, Nash equilibrium across all EU countries may be assumed ($\lambda = 1$). The regulatory variables R_{ts} enter the supply equation as exogenous linear price shifters.[26] Therefore, pricing equation which corresponds to first order condition (5.5) may be written as

$$p_{ts} + \frac{1}{N_{ts}}\frac{\lambda}{\alpha} + R_{ts}\delta = MC_{ts} \tag{5.7}$$

where the linear marginal cost function is assumed to have a country-specific constant component

$$MC_{ts} = W_{ts}\phi + D_s\gamma + \omega_{ts} \tag{5.8}$$

$R_{ts} = [Service_{ts}, Portab_{ts}, Libera_{ts}]$ is the set of regulatory variables, $W_{ts} = [Labor_{ts}$, $Bond_{ts}$, $Elect_{ts}$, $Time_t$, $SMP_{ts}]$ represents cost determinants, D_s are country dummies and ω_{ts} the unobservable cost shifters. The structural model (5.6) and (5.7) may be

[26] In this way, a direct effect of regulatory variables on prices without multiplication by the reversed number of operators can be estimated.

transformed into a reduced form specification with linear demand and supply

$$log(Q_{ts}) = -\frac{1}{N_{ts}}\lambda - R_{ts}\delta\alpha + W_{ts}\phi\alpha + D_s\gamma\alpha + X_{ts}\beta + \bar{\epsilon}_{ts} \tag{5.9}$$

$$p_{ts} = -\frac{1}{N_{ts}}\frac{\lambda}{\alpha} - R_{ts}\delta + W_{ts}\phi + D_s\gamma + \overline{\omega}_{ts}, \tag{5.10}$$

where $\bar{\epsilon}_{ts} = \epsilon_{ts} + \alpha\omega_{ts}$ and $\overline{\omega}_{ts} = \omega_{ts}$ are the transformed unobservable demand and supply shifters. This transformation allows instrumental variables estimation of the simultaneous system of demand and supply to be avoided. For consistency of the OLS estimates, the unobservables in both equations must be uncorrelated with the explanatory variables but they can be correlated with each other. Thus, SURE estimation method (see table 5.7) of both equations (5.9) and (5.10) should be more efficient than a simple OLS regression (see tables 5.5 and 5.6).

The variables, which turn out to be significant in reduced form estimation are used in the structural estimation. Referring to discussion in the previous subsection, two specifications of the pricing equation (5.5) are considered. In the first case, all countries are assumed to have common market conduct

$$p_{ts} = -\frac{1}{N_{ts}}\frac{1}{\alpha}[\eta + R_{ts}\delta] + W_{ts}\phi + D_s\gamma + \omega_{ts} \tag{5.11}$$

Hence, the structural model consists of equations (5.6) and (5.11). In the second case, market conduct is country-specific and there is a common intercept in the cost function for all countries:

$$p_{ts} = -\frac{1}{N_{ts}}\frac{1}{\alpha}[D_s\eta + R_{ts}\delta] + W_{ts}\phi + \omega_{ts} \tag{5.12}$$

The structural model consists of equations (5.6) and (5.12).

I use an ordinary least squares estimation method (OLS) and two stage least squares (2SLS) to estimate at first the demand equation (5.6) with pooled data as shown in table (5.9). The reason for estimating demand with common constant for all countries is that, country dummies in the reduced form estimation explain only 12% of variation in subscriptions (see specification IV in table 5.5). Moreover, the insignificance of dummies cannot be rejected. This is an argument in favor for specification (5.6). Next, I estimate jointly demand (5.6) and supply (5.11) using seemingly unrelated regression method (SURE) and non-linear three stage least squares (N3SLS) to account for a possible correlation of the error terms in both equations and for endogeneity of explanatory variables (see table 5.10). Similarly, I estimate second specification of structural model (5.6) and (5.12), which results are presented in table (5.11). In the estimation I restrict coefficients to be the same in both time and country dimension. This is necessary because of data limitations. It implies that the coefficients may be interpreted only as average values across the EU countries in the time period analyzed.

Consistent estimates of structural model require an instrumental variables method. Following set of instruments is used to estimate the demand side $Z_{ts} = [log(GDP_{ts})$ $log(Pop_{ts})$ $Labor_{ts}$ $Bond_{ts}$ $Elect_{ts}$ $Libera_{ts}]$, that is respectively, GDP per capita in \$US PPP as a logarithm, population as a logarithm, cost determinants: cost of labor, capital and electricity, and a dummy for liberalization of fixed telephony. In the joint demand-supply estimation, I use the set of instruments defined above plus a dummy for number portability and country dummies $Z_{ts} = [log(GDP_{ts})$ $log(Pop_{ts})$ $Labor_{ts}$ $Bond_{ts}$ $Elect_{ts}$ $Libera_{ts}$ $Portab_{ts}$ $D_1, ...D_{14}]$. The instruments cannot be correlated with the unobservable demand and cost shifters and should be highly correlated with the endogenous variables. The instruments GDP per capita and country population are exogenous and apparently correlated with mobile subscriptions and prices (these variables were used in the former studies). As I noticed in the previous subsection, the regulatory variables should be exogenous and uncorrelated with the error terms in both demand and supply equation. Finally, there is no reason for cost determinants to correlate with unobserved shocks in telecommunications industry. The Hausman specification test for demand (see table 5.9) and for demand-supply estimation (see table 5.10 and 5.11) suggests that the IV estimation method is not necessary to use. Thus, SURE estimation should provide consistent estimates.

5.4 Results

5.4.1 The Reduced Form

I separately estimate the demand and supply sides using panel data analysis with fixed and random effects. In the fixed effects formulation of the demand side, the significant exogenous variables explain about 93% of the variation in subscriptions (see specification III in table 5.5). The hypothesis of insignificant fixed effects can be rejected with a high level of significance for all specifications. The fit for the random effects specification is also very good with an R-squared of 0.89 (see table 5.8). However, the Hausman test for random effects rejects the null hypothesis of random individual effects with an m-value equal to 10.94. The supply side regression has a worse fit at $R^2 = 0.80$ in the case of fixed effects specification, but still high percentage of variation in prices can be explained (see specification II in table 5.6). The fit in the random effects specification is much worse with an R-squared of 0.58. There is much more unexplained noise in the pricing policies of the firms than in the consumers' decision to purchase mobile phones. The first source of the unobservable supply shifters may be the regulatory policy. There are some regulatory issues that cannot be easily quantified and implemented in the model. Moreover, firms apply dynamic strategies while the model I estimate is based on the assumption of a static equilibrium. Each country seems to have a specific competitive environment, which is difficult to explain using an econometric model.

The most important result indicating the impact of regulation on industry performance is the significance of a dummy for liberalization on both the demand and supply sides. Liberalization itself should not be seen exclusively as opening up fixed-line telephony for competition. Many other regulatory processes have been initiated and the power of NRAs has been strengthened. This variable also suggests possible dependencies between mobile and fixed-line telephony. Liberalization apparently causes an increase in competition and a drop in the residential expenditures on the fixed-line services, which may have induced consumers to buy mobile phones as an additional service. Through negative impact on prices it also has a positive impact on the demand side. Therefore, countries that liberalized their fixed-line industry earlier enjoy lower prices for mobile services and a higher level of consumer subscriptions. Apart from the potential welfare gains in the fixed-line industry, liberalization generates additional surplus in the mobile telephony.

Referring to the earlier discussion, some other potential regulatory sources for price changes may be considered: a dummy for the implementation of number portability (MNP), a dummy for the presence of airtime resellers (Service), and a dummy for the regulation of interconnection charges through the designation with significant market power (SMP). The first two regulatory tools can reduce the price of mobile services. Moreover, (Service) may also directly influence the demand for mobile subscriptions. (SMP) could influence prices as a cost factor. However, in the supply regression, only (MNP) turns out to have a significant negative impact on prices. Competition is fiercer and prices are lower in countries that already enforce the portability of mobile numbers. MNP raises consumer surplus, but to evaluate total welfare changes, the cost of implementation must be taken into account. The cost-benefit analysis of number portability is not a trivial issue and is currently subject to debate between regulators and market players. (MNP) turns out to be insignificant on the demand side even though it is a significant price determinant. This might be due to high correlation with other explanatory variables on the demand side such as the time trend (Time) and the liberalization dummy (Libera) as presented in table 5.4.

The presence of airtime resellers surprisingly does not have any impact on price and demand, which suggests that such regulation is unneeded. The dummy for regulation of interconnection charges through the SMP designation has a significant positive impact on demand. This effect should come from the supply side, but the estimate of (SMP) in the pricing regression is insignificant, which indicates again possible multicollinearity of explanatory variables. In particular, SMP is highly correlated with the dummy for the liberalization of fixed-line, which may cause difficulty in estimating both coefficients (see table 5.4). Still, an SMP designation can be considered as an important regulatory tool contributing to growth in mobile subscriptions.

Gruber and Verboven (2001) find a significant negative impact of fixed-line subscriptions on the demand for mobile phones together with an insignificant impact of the GDP per capita. The present study suggests a contradicting result; insignificant fixed-line penetration and a significant coefficient for GDP per capita. However, there is a high correlation of fixed-line subscriptions with GDP per capita, as shown in table 5.4. Thus, it could be impossible to estimate the coefficients for both variables. GDP per capita has a significant positive impact on mobile subscriptions across the EU countries.[27] However, when (GDP) is excluded, the estimate of fixed-line penetration becomes positive with a significance level of 0.13 and its significance increases in the estimation without fixed effects. This is because the fixed-line penetration does not vary too much in time and therefore represents a kind of fixed effect. The other reason for such differences in results may be drastic industry transformation which took place through this time. Gruber and Verboven (2001) analyze the time period up to 1997, when the average penetration rate did not surpass 18%. In the time period I analyze mobile subscriptions grew exponentially and in most countries they surpassed a penetration rate of 70%. In addition, the decreasing prices of fixed-line and mobile services in the past years may have allowed consumers to afford access to both networks. Moreover, the origins of use of fixed-line services nowadays are different. The fixed-line connection is, to an increasing extent, used for access to the Internet. Thus, mobile and fixed-line services could be seen as complements rather than substitutes, even though they may indeed compete with each other in voice telephony services.

The time trend, which should account for the technological innovation, is significant and positive on the demand side. Thus, technological progress has been constantly

[27] To account for possible differences in price levels across countries, I calculate GDP per capita in $US PPP, which should better measure the potential income effects in cross-country analysis than GDP in $US. Gruber and Verboven (2001) use GDP per capita without transformation.

raising consumer valuation of mobile services and has significantly contributed to an increase in demand. On the supply side, I use the time trend to account for a constant decrease in the cost of providing mobile services. However, the coefficient of the time trend on the supply side is insignificant and in the time period analyzed there was no decrease in prices resulting from technological innovation.

The country dummies themselves explain 44% of price variation, which indicates a significant difference in the price levels across countries and may have an origin in different levels of marginal costs (see specification IV in table 5.6). The dummies could also account for differences in the level of market competition across countries. In the demand regression, country dummies explain only 12% of variation in mobile subscriptions (see specification IV in table 5.5). All dummies are measured relative to the reference country (UK) represented by the intercept in both the demand and supply equations. Finally, the marginal cost of providing mobile services depends on the cost of labor and the cost of capital. (Bonds) turns out to be insignificant in the pricing regression, but both cost variables are significant and negative on the demand side. It should be pointed out that there is not much variation in cost of labor, and cost of capital over time. Thus, it is hard to get significant estimates of these three variables within one equation.

The coefficient in front of the inverse number of competitors in the supply equation $\frac{\lambda}{\alpha}$ is insignificant, and similarly in the demand equation. Thus, the null hypothesis of the collusion parameter being equal to zero ($\lambda = 0$) cannot be rejected, and the average collusiveness across the EU countries in this time period could be considered close to perfect competition. However, this conclusion would be wrong because the regulatory variables drive prices down even further, which would imply that firms set prices below marginal costs. Therefore, the country dummies may indeed include some information about average industry conduct and this result should instead be subscribed to the identification problem on the supply side.

To sum up, the differences in the price variation between specifications III and IV in table 5.6 are explained by the explanatory variables other than fixed effects: cost factors and regulation. The regulatory policy significantly contributed to a decrease in prices of mobile services. Namely, the liberalization of the telecommunications industry contributed to an average decline in prices across Member States of around 16 $US PPP and the introduction of mobile portability caused an average drop in prices of around 7 $US PPP. Of course, these effects may be different from country to country as the price levels differ significantly. The remaining price changes arise from changes in marginal costs.

5.4.2 The Structural Form

The estimation of the reduced form demand and supply equations restricted the set of potential explanatory variables to significant ones. It also signalled the identification problem in the estimation of the supply equation. Thus, I estimate at first the demand side (see table 5.9). The demand for mobile subscriptions might be simply explained by prices, constant and time trend. It is driven to a large extent by decreasing prices of mobile subscriptions. In this specification of the demand function the price elasticities depend on the level of prices. Thus, over time there is a decrease in elasticities, which is proportional to the decrease in market prices (see table 5.12). The estimate of price coefficient in the demand equation $\alpha = 0.00921$ (see SURE estimation results in table 5.10) allows to identify the parameter of market conduct in the supply equation. This coefficient should remain unchanged in the joint demand-supply estimation, given that the supply specification is correct. Moreover, annual increase in mobile subscriptions due to technological innovation accounts for about 25%.

The estimation of the supply side is problematic due to all assumption which had to be made to derive estimable supply equation. As already mentioned, a static conjectural variation equilibrium is imposed, which may cause a bias in estimates of conduct parameters. Moreover, country dummies in the marginal cost function and country-specific collusion parameters cannot be identified at the same time. Therefore, two different formulations of the supply side are considered. First, conjectural variation is defined as $\lambda_{ts} = [\eta + R_{ts}\delta]$ and the supply equation is given by (5.12). In this case, similarly to reduced form estimation, the regulation drives average collusion parameter λ_{ts} below zero, which suggests that firms set prices below marginal costs and have negative markups (see table 5.11). Obviously, marginal costs must be overestimated. Hence, the assumption of common conduct across the Member States must be very severe. In the second specification, I assume that conjectural variation is represented by $\lambda_{ts} = [D_s\eta + R_{ts}\delta]$ and the supply side is given by (5.11). The estimation results are presented in table 5.10. In this formulation the conjectural variation takes values between 0 and 1 for almost all countries in year 1998 and over time λ_{ts} gets closer to zero due to regulation. The regulatory variables (Libera) and (Portab) have significant negative impact on market collusiveness and decrease prices. For some countries, the hypothesis of conjectural variation equal to zero cannot be rejected. The impact of regulation on prices is unquestioned, but the results imply again that mobile telephony in most countries is perfectly competitive. In some cases, the collusion parameter λ_{ts} becomes even negative (see table 5.13), which implies negative markups as presented in table 5.15. This result is not plausible from theoretical point of view and industry practice. The marginal costs must be overestimated, which makes the interpretation of conduct parameters questionable.

In any specification, given short amount of data, it is not possible to disentangle prices into marginal cost and markup. Therefore, the main conclusion of this analysis should be, that the regulation, such as liberalization of fixed-line industry and implementation of number portability, has a significant negative impact on industry collusiveness and prices. Moreover, the structural model provides information about average price elasticities presented in table 5.12. The average industry marginal costs (see table 5.14) and the average market collusiveness (see table 5.13) may not represent trustable values. Nevertheless, the ordering of countries according to conduct values can still have some meaning. Indeed, the ordering seems to be plausible. The

Scandinavian countries, which are were most advanced in the startup and adoption of mobile services have most competitive industries. The Member States which are perceived as less advanced in the adoption of mobile telephony and had difficulties with liberalization of telecommunications industry, such as Portugal, Greece, Ireland and Spain, are among least competitive countries.[28] These countries have higher prices than Scandinavian countries and at the same time lower costs, in particular, the cost of labor, which implies higher markups.

It must be noted that this is the only analysis which tries to evaluate the competitiveness of mobile telephony across the European Union using a theory-based framework and econometric methods. It may be considered as an alternative to the other descriptive studies conducted by the EC and consultancy firms. In particular, it provides a broader insight into determinants of prices and competitiveness across the EU than Teligen's "Index of Competitive Development".

5.5 Conclusion

The mobile telephony in the EU is perceived as an exemplar for a successful implementation and regulation of a new technology. However, so far not much empirical evidence has been provided on the importance of regulation for the development and competition in mobile telephony. In this study I analyze the impact of regulatory policy and country-specific factors on the diffusion and competitiveness of mobile telecommunications services across the European Union.

I estimate a reduced form and structural model of mobile industry using panel data for the EU countries from 1998 to 2002. The variation in mobile subscriptions and prices seems to be well explained using the reduced form panel data analysis. I find that the regulatory policy significantly influences the level of prices and the demand for mobile services. In particular, the liberalization of fixed telephony has a

[28]Spain, Ireland, Greece and Portugal were granted additional transitional periods for the liberalization of telecommunications industry to allow for necessary structural adjustments.

negative impact on price and a positive impact on the diffusion. Therefore, the effects of liberalization are not exclusively restricted to fixed telephony, but also contribute to positive developments in the mobile industry. Moreover, the implementation of number portability in the mobile telephony has a negative impact on prices. This result confirms that a decrease in consumer switching costs raises competition and causes prices to fall. Such a decrease in prices was expected by regulators but so far has been not proven empirically. Furthermore, regulation of interconnection charges through the designation of mobile operators with significant market power increases the demand for mobile telephony. The raise in demand should result from the decrease in costs and prices caused by SMP designation and lowered access charges but I do not find any significant impact of this variable on prices. Nevertheless, the regulation resulting from SMP designation has a positive impact on the development of the mobile industry. The allowance of independent service providers does not lower the prices nor increases demand. Therefore, the industry may perform equally well without such regulation. Moreover, due to technological innovation the mobile industry has enjoyed substantial annual increases in demand.

In the estimation of structural model, the regulatory variables have a significant negative impact on the industry collusiveness. However, I am not able to disentangle adequately prices into marginal cost and markup. The conjectural variation is underestimated, which implies zero and negative markups in case of many countries. Still, conduct estimates enable to compare the EU countries in respect to the level of competitiveness. The ordering seems to be plausible. This econometric analysis of competitiveness across the European Union may provide a credible alternative to other descriptive studies.

Empirical evidence on the importance of regulation for the performance of the mobile industry should be of particular interest to regulators. To the best of my knowledge, this is the only study that explains the determinants of the variation in prices of mobile services across the European Union. It provides some guidelines for the design of regulatory policy. This is particularly important for the ten new Member States, which are about to adjust their telecommunications policy to the common regulation in the European Union and for the future regulation of 3G services.

5.6 Appendix

Figure 5.1: Mobile penetrations and monthly bills in $US PPP across the EU in 1998-2002

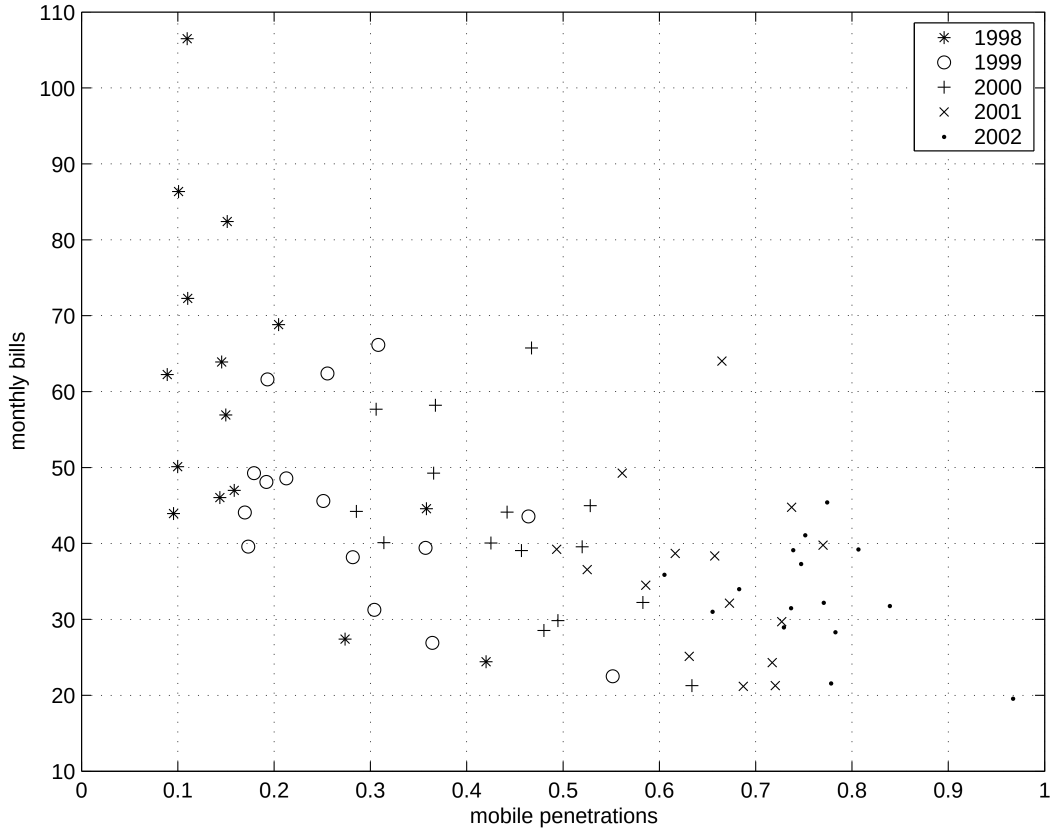


Table 5.1: Source of data

Variables	Source
Penetration of mobiles as a logarithm (Mobile)	ITU database
Price of mobile services (Mobbill)	based on Teligen reports
Penetration of mainline as a logarithm (Fixed)	ITU database
Number of mobile network operators (N) inverse number of operators (N)	EU reports
GDP per capita in $US PPP as a logarithm (GDP)	ITU database
Population size as a logarithm (Pop)	ITU database
Time trend (Time)	
Time passed since entry of the first digital operator in years (Digital)	www.gsmworld.com
Dummy for liberalization of fixed telephony market (Libera)	ETO
Dummy for permission of airtime resellers (Service)	EU reports
Dummy for implementation of number portability in mobile networks (MNP)	ETO
Dummy for designation with SMP in interconnection market (SMP)	EU reports
10-year government bond yield (Bond)	Eurostat & OECD
Hourly labor compensation costs in industry in $US PPP (Labor)	US Department of Labor
Electricity prices for industrial users in $US PPP (Elect)	Eurostat

Table 5.2: Liberalization and number portability

Country	Liberalization	Portability	GSM startup
Austria	01.1998	06.2003	12.1993
Belgium	01.1998	10.2002	01.1994
Denmark	1995	06.2001	07.1992
Finland	1994	08.2003	07.1992
France	01.1998	06.2003	07.1992
Germany	01.1998	11.2002	06.1992
Greece	01.2001	07.2003	07.1993
Ireland	12.1998	06.2003	03.1993
Italy	01.1998	03.2002	10.1992
Luxembourg	07.1998	07.2003	07.1993
Netherlands	01.1998	04.1999	07.1994
Portugal	01.2000	01.2002	10.1992
Spain	12.1998	11.2000	07.1995
Sweden	1993	09.2001	09.1992
UK	1996	01.1999	07.1992

Source: ETO and ECC (Electronic Communications Committee) and www.gsmworld.com

Table 5.3: Simple Statistics

Variable	N	Mean	Std Dev	Sum	Min	Max
Mobbill	75	43.23	16.35	3243	19.68	106.86
Mobile	75	3.65	0.65	274.12	2.18	4.57
Pop	75	16.35	1.34	1227	12.95	18.22
GDP	75	10.12	0.22	759.01	9.62	10.79
Fixed	75	3.99	0.18	299.37	3.69	4.36
Time	75	3.00	1.42	225.00	1.00	5.00
Digital	75	6.73	1.66	505.00	2.50	9.50
Service	75	0.41	0.49	31.00	0	1.00
MNP	75	0.13	0.34	10.00	0	1.00
Libera	75	0.76	0.42	57.00	0	1.00
1/N	75	0.35	0.12	26.68	0.20	1.00
Labor	75	19.20	5.56	1440	6.41	30.80
Bond	75	5.37	0.87	403.40	4.50	9.90
Elect	75	6.28	1.27	471.00	3.00	9.00
SMP	75	0.26	0.44	20.00	0	1.00

Table 5.4: Correlation matrix

	Mobbill	Mobile	Pop	GDP	Fixed	Time	Digital	Service
Mobbill	1.00	-0.66	0.28	-0.43	-0.47	-0.52	-0.55	-0.45
Mobile	-0.66	1.00	-0.14	0.09	0.21	0.88	0.83	0.20
Pop	0.28	-0.14	1.00	-0.51	-0.28	0.00	0.03	-0.20
GDP	-0.43	0.09	-0.51	1.00	0.54	0.01	0.06	0.44
Fixed	-0.47	0.21	-0.28	0.54	1.00	0.12	0.29	0.73
Time	-0.52	0.88	0.00	0.01	0.12	1.00	0.85	0.03
Digital	-0.55	0.83	0.03	0.06	0.29	0.85	1.00	0.28
Service	-0.45	0.20	-0.20	0.44	0.73	0.03	0.28	1.00
MNP	-0.21	0.30	0.18	-0.02	0.15	0.36	0.20	0.14
Libera	-0.71	0.67	0.01	0.32	0.35	0.55	0.56	0.34
1/N	0.23	-0.46	-0.47	0.24	-0.08	-0.49	-0.51	-0.07
Labor	-0.03	-0.43	0.06	0.46	0.28	-0.49	-0.43	0.26
Bond	0.35	-0.39	-0.00	-0.34	-0.11	-0.36	-0.30	-0.11
Elect	0.26	-0.17	0.15	0.11	-0.43	0.02	-0.12	-0.44
SMP	-0.39	0.47	-0.00	-0.03	0.01	0.38	0.35	0.04
	MNP	Libera	1/N	Labor	Bond	Elect	SMP	
Mobbill	-0.21	-0.71	0.12	-0.03	0.35	0.26	-0.39	
Mobile	0.30	0.67	-0.43	-0.43	-0.39	-0.17	0.47	
Pop	0.18	0.01	-0.52	0.06	-0.00	0.15	-0.00	
GDP	-0.02	0.32	0.35	0.46	-0.34	0.11	-0.03	
Fixed	0.15	0.35	-0.13	0.28	-0.11	-0.43	0.01	
Time	0.36	0.55	-0.50	-0.49	-0.36	0.02	0.38	
Digital	0.20	0.56	-0.57	-0.43	-0.30	-0.12	0.35	
Service	0.14	0.34	-0.13	0.26	-0.11	-0.44	0.04	
MNP	1.00	0.22	-0.35	-0.16	-0.13	-0.05	0.02	
Libera	0.22	1.00	-0.33	0.05	-0.47	-0.17	0.33	
1/N	-0.31	-0.49	1.00	0.09	0.23	0.05	-0.17	
Labor	-0.16	0.05	0.30	1.00	-0.16	0.08	-0.10	
Bond	-0.13	-0.47	0.05	-0.16	1.00	-0.06	-0.13	
Elect	-0.05	-0.17	0.07	0.07	-0.06	1.00	-0.29	
SMP	0.02	0.33	-0.12	-0.10	-0.13	-0.29	1.00	

Table 5.5: Reduced form estimation – demand side

	I	II	III	IV		I	II	III	IV
Austria	3.389	0.366	0.246	0.066	Intercept	-33.01	-8.118	-6.594	4.02
t-value	0.46	2.05	2.07	0.21	t-value	-0.50	-1.85	-1.63	18.4
Belgium	2.965	0.291	0.211	-0.23	Fixed	0.3205	0.6034		
t-value	0.45	1.88	1.67	-0.76	t-value	0.42	0.90		
Denmark	3.680	0.035	0.139	0.050	GDP	1.0581	1.1079	1.2054	
t-value	0.41	0.21	1.19	0.16	t-value	2.27	2.53	2.84	
Finland	3.924	0.373	0.348	0.223	Pop	1.4987			
t-value	0.43	2.95	2.83	0.72	t-value	0.40			
France	-0.36	-0.39	-0.39	-0.27	Time	0.1470	0.1476	0.1511	
t-value	-1.84	-3.75	-3.81	-0.90	t-value	5.64	7.03	7.34	
Germany	-0.18	0.224	0.267	-0.27	Service	0.0016			
t-value	-0.15	1.65	2.10	-0.88	t-value	0.01			
Greece	2.787	0.224	0.206	-0.14	MNP	0.0402			
t-value	0.44	1.16	1.08	-0.47	t-value	0.53			
Ireland	3.887	-0.25	-0.41	-0.05	SMP	0.1488	0.1371	0.1383	
t-value	0.38	-1.23	-3.49	-0.17	t-value	2.12	2.16	2.18	
Italy	0.327	0.261	0.132	0.132	Libera	0.1551	0.1746	0.1741	
t-value	1.27	1.47	1.27	0.43	t-value	1.64	2.11	2.11	
Luxemb.	6.950	-0.55	-0.47	0.119	1/N	-0.090			
t-value	0.38	-1.93	-1.73	0.39	t-value	-0.17			
Netherl	2.149	0.154	0.190	-0.10	Labor	-0.075	-0.076	-0.079	
t-value	0.44	1.30	1.70	-0.33	t-value	-5.53	-6.44	-6.76	
Portugal	2.601	-0.00	-0.17	0.024	Bonds	-0.157	-0.155	-0.162	
t-value	0.40	-0.01	-1.04	0.08	t-value	-2.77	-2.97	-3.13	
Spain	0.515	0.030	-0.13	-0.21	Elect	-0.046			
t-value	0.36	0.14	-0.98	-0.70	t-value	-1.15			
Sweden	2.809	0.017	0.163	0.179					
t-value	0.39	0.09	1.41	0.58					
R-Square	0.931	0.928	0.927	0.120					
MSE	0.023	0.021	0.021	0.238					
DFE	48	53	54	60					
F-value	3.66	5.63	5.94	0.59					
signif.	0.004	0.001	0.001	0.86					

Table 5.6: Reduced form estimation – supply side

	I	II	III		I	II	III
Austria	-17.039	-12.71	0.5851	Intercept	22.626	27.037	39.9
t-value	-1.28	-2.17	0.07	t-value	0.51	1.81	6.64
Belgium	-21.859	-16.41	-0.322	Time	0.8170		
t-value	-1.49	-2.70	-0.04	t-value	0.27		
Denmark	-20.840	-18.72	-11.75	Service	-2.293		
t-value	-2.84	-3.39	-1.38	t-value	-0.23		
Finland	-31.118	-26.38	-17.72	MNP	-8.479	-8.445	
t-value	-3.17	-4.56	-2.08	t-value	-1.90	-2.07	
France	-6.5398	-2.762	4.5668	SMP	1.4214		
t-value	-0.56	-0.47	0.54	t-value	0.35		
Germany	-9.8457	-8.004	8.7618	Libera	-15.40	-15.53	
t-value	-0.77	-1.27	1.03	t-value	-3.82	-4.76	
Greece	-4.4034	-1.986	14.547	1/N	7.9171		
t-value	-0.34	-0.27	1.71	t-value	0.48		
Ireland	-2.8797	-0.233	7.5849	Labor	1.3879	1.1091	
t-value	-0.24	-0.04	0.89	t-value	1.21	2.74	
Italy	-8.7529	-4.761	5.9391	Bonds	2.7300	2.5301	
t-value	-0.73	-0.83	0.70	t-value	1.31	1.65	
Luxembourg	-23.042	-19.95	-10.38	Elect	-0.595		
t-value	-2.45	-3.43	-1.22	t-value	-0.26		
Netherlands	1.57683	5.0761	13.307				
t-value	0.14	0.88	1.57				
Portugal	20.1836	20.679	24.587				
t-value	1.28	2.55	2.89				
Spain	0.76807	4.4233	9.9742				
t-value	0.06	0.78	1.17				
Sweden	-13.742	-9.735	-4.522				
t-value	-1.49	-1.78	-0.53				
R-Square	0.8044	0.8022	0.4435				
MSE	74.75	68.84	180.75				
DFE	51	56	60				
F-value	2.71	5.90	3.42				
significance	0.0048	0.0001	0.0004				

Table 5.7: Reduced form estimation – SURE

	Demand	Supply		Demand	Supply
Austria	0.24274	-12.717	Intercept	-6.2061	24.4460
t-value	2.04	-2.17	t-value	-1.54	1.64
Belgium	0.20503	-16.603	GDP	1.16430	
t-value	1.62	-2.73	t-value	2.75	
Denmark	0.14320	-18.837	Time	0.15191	
t-value	1.23	-3.41	t-value	7.39	
Finland	0.33882	-26.441	Libera	0.17350	-14.713
t-value	2.76	-4.57	t-value	2.10	-4.52
France	-0.3997	-2.3728	SMP	0.14556	
t-value	-3.84	-0.40	t-value	2.30	
Germany	0.26283	-8.2642	Portab		-8.0470
t-value	2.07	-1.31	t-value		-1.98
Greece	0.19308	-0.8090	Labor	-0.0781	1.18431
t-value	1.01	-0.11	t-value	-6.69	2.93
Ireland	-0.4083	0.52692	Bonds	-0.1605	2.56974
t-value	-3.47	0.08	t-value	-3.11	1.68
Italy	0.12834	-4.5451			
t-value	1.23	-0.79			
Luxembourg	-0.4472	-19.709			
t-value	-1.65	-3.39			
Netherlands	0.18959	4.81950			
t-value	1.70	0.84			
Portugal	-0.1817	22.0945			
t-value	-1.08	2.73			
Spain	-0.1438	4.95399			
t-value	-1.08	0.87			
Sweden	0.1551	-9.7211			
t-value	1.34	-1.78			
MSE	0.0217	68.84			
DFE	54	56			
Hausman SURE	2.05				
$Pr > \chi^2$	1.00				

Table 5.8: Random effects specification - separate estimation of demand and supply

	Demand	Supply
Intercept	-2.10556	38.4175
t-value	-1.03	3.07
significance	0.3051	0.0030
Fixed	0.409969	-37.6189
t-value	1.40	-2.99
significance	0.1655	0.0039
GDP	0.50423	
t-value	2.09	
significance	0.0403	
Time	0.178847	
t-value	9.41	
significance	0.0001	
MNP		-8.46858
t-value		-2.19
significance		0.0320
SMP	0.163281	-2.76449
t-value	2.78	-0.83
significance	0.0070	0.4070
Libera	0.20504	-18.7234
t-value	2.42	-5.89
significance	0.0180	0.0001
Labor	-0.0517	0.441377
t-value	-5.81	1.35
significance	0.0001	0.1823
Bonds	-0.09283	2.25218
t-value	-1.97	1.47
significance	0.0526	0.1474
R-Square	0.8921	0.5829
MSE	0.0234	74.15
DFE	67	69
Hausman m-value	10.94	.
significance	0.0903	.

Table 5.9: Demand side estimation

	OLS	N2SLS	OLS	N2SLS
α	-0.00799	-0.01596	-0.00781	-0.01033
t-value	-3.62	-2.71	-4.20	-3.86
significance	0.0006	0.0086	0.0001	0.0002
Constant	6.484454	8.851053	3.62801	3.655373
t-value	4.01	3.67	28.09	19.51
significance	0.0002	0.0005	0.0001	0.0001
GDP	-0.19478	-0.30005		
t-value	-1.28	-1.55		
significance	0.2051	0.1263		
Fixed	-0.01655	-0.27902		
t-value	-0.09	-0.63		
significance	0.9268	0.5338		
Pop	-0.04977	-0.04191		
t-value	-2.28	-1.68		
significance	0.0259	0.0983		
Time	0.233285	0.221621	0.233043	0.260301
t-value	10.61	4.55	10.89	8.66
significance	0.0001	0.0001	0.0001	0.0001
Objective	0.0442	0.001259	0.0477	0.006033
MSE	0.048	0.0597	0.0497	0.0548
DF	69	69	72	72
Hausman		10.25		11.23
$Pr > \chi^2$		0.114		0.106

Table 5.10: Joint demand-supply estimation – country-specific conduct

	OLS	SUR	N3SLS		OLS	SUR	N3SLS
α	-0.0078	-0.0092	-0.0097	Ireland	-0.0914	-0.1165	-0.1479
t-value	-4.22	-4.98	-4.38	t-value	-0.59	-0.59	-0.49
Intercept	3.62801	3.70756	3.74702	Italy	-0.1671	-0.2299	-0.2871
t-value	28.19	28.82	24.58	t-value	-1.10	-1.19	-1.16
Time	0.23304	0.22675	0.22128	Luxemb.	-0.4691	-0.5428	-0.6127
t-value	10.93	10.62	9.42	t-value	-2.43	-2.40	-1.42
Libera	-0.1917	-0.2517	-0.2946	Netherl.	0.28000	0.34559	0.18332
t-value	-2.51	-2.76	-1.94	t-value	1.65	1.68	0.93
Portab	-0.1918	-0.2068	-0.1845	Portugal	0.37166	0.34300	0.33781
t-value	-1.77	-1.58	-1.52	t-value	1.89	1.47	1.00
Austria	-0.3345	-0.3769	-0.4181	Spain	-0.0257	0.00020	0.00943
t-value	-1.95	-1.82	-1.94	t-value	-0.18	0.00	0.03
Belgium	-0.3853	-0.3517	-0.3718	Sweden	-0.2716	-0.3408	-0.4028
t-value	-2.17	-1.70	-1.48	t-value	-1.71	-1.74	-1.66
Denmark	-0.5050	-0.5515	-0.5686	η	0.55767	0.66625	0.78596
t-value	-2.64	-2.54	-2.59	t-value	2.41	2.43	1.18
Finland	-0.6294	-0.7335	-0.8053	Constant	3.03072	1.43069	-0.6529
t-value	-2.96	-3.08	-2.79	t-value	0.28	0.12	-0.06
France	-0.0808	-0.0074	0.02498	Labor	0.82713	0.69350	0.84576
t-value	-0.52	-0.04	0.11	t-value	2.28	1.75	1.43
Germany	-0.0464	0.07662	0.01814	Bonds	2.62557	3.34817	2.90789
t-value	-0.26	0.34	0.07	t-value	1.66	1.97	1.56
Greece	-0.0678	-0.1237	-0.0979				
t-value	-0.42	-0.61	-0.43				
mse demand	0.0494	0.498	0.501	Hausman		10.59	25.89
mse supply	59.908	64.06	72.10	$Pr > \chi^2$		0.9861	0.3061
df demand	72.5	72.5	72.5				
df supply	54.5	54.5	54.5				
Objective	43.58	1.4898	0.5987				

Table 5.11: Joint demand-supply estimation – country-specific marginal cost

	OLS	SUR	N3SLS		OLS	SUR	N3SLS
α	-0.00781	-0.00959	-0.00972	Ireland	3.9502	3.1919	-0.294
t-value	-4.22	-5.20	-4.35	t-value	0.57	0.45	-0.03
Intercept	3.6280	3.7383	3.74453	Italy	-2.350	-3.972	-6.229
t-value	28.19	29.12	24.50	t-value	-0.38	-0.63	-0.83
Time	0.2330	0.22197	0.22175	Luxemb.	-18.14	-17.91	-20.50
t-value	10.93	10.40	9.42	t-value	-2.20	-2.11	-1.06
Libera	-0.244	-0.3293	-0.3855	Netherl.	3.3203	4.0638	4.7180
t-value	-2.68	-3.10	-2.14	t-value	0.54	0.65	0.75
Portab	-0.183	-0.2137	-0.2879	Portugal	28.476	23.937	17.087
t-value	-1.41	-1.35	-1.82	t-value	3.40	2.77	1.46
Austria	-11.71	-11.400	-12.066	Spain	8.0963	8.8001	7.3330
t-value	-1.90	-1.79	-1.99	t-value	1.31	1.38	0.79
Belgium	-15.26	-11.307	-9.7588	Sweden	-7.773	-8.653	-9.647
t-value	-2.32	-1.67	-1.28	t-value	-1.32	-1.43	-1.37
Denmark	-18.10	-16.591	-16.04	Cost	6.7119	5.4861	12.264
t-value	-3.09	-2.75	-2.78	t-value	0.49	0.39	0.92
Finland	-24.75	-24.187	-24.661	Labor	1.3912	1.2349	0.9366
t-value	-3.95	-3.75	-3.26	t-value	3.19	2.72	1.45
France	0.9286	3.83445	3.41937	Bonds	2.7763	3.4707	3.2636
t-value	0.15	0.59	0.45	t-value	1.68	2.04	1.71
Germany	-7.462 -	3.6526	-1.5645	η	0.1560	0.2161	0.2968
t-value	-1.11	-0.53	-0.21	t-value	1.28	1.43	0.63
Greece	5.1615	2.65033	-1.4055				
t-value	0.71	0.35	-0.18				
mse demand	0.0494	0.0500	0.0501	Hausman		46.88	-44.9
mse supply	77.453	81.42	88.69	$Pr > \chi^2$		0.0023	.
df demand	72.5	72.5	72.5				
df supply	54.5	54.5	54.5				
Objective	56.33	1.5822	0.5949				

Table 5.12: Price elasticities

Country	1998	1999	2000	2001	2002
Austria	-0.416	-0.344	-0.359	-0.359	-0.352
Belgium	-0.399	-0.360	-0.364	-0.332	-0.337
Denmark	-0.248	-0.244	-0.270	-0.228	-0.285
Finland	-0.221	-0.204	-0.193	-0.193	-0.196
France	-0.453	-0.438	-0.446	-0.357	-0.324
Germany	-0.786	-0.399	-0.403	-0.311	-0.308
Greece	-0.566	-0.557	-0.529	-0.446	-0.375
Ireland	-0.580	-0.566	-0.400	-0.347	-0.262
Italy	-0.622	-0.359	-0.407	-0.407	-0.288
Luxembourg	-0.425	-0.284	-0.259	-0.191	-0.177
Netherlands	-0.963	-0.441	-0.363	-0.292	-0.355
Portugal	-0.741	-0.596	-0.596	-0.578	-0.413
Spain	-0.659	-0.446	-0.524	-0.353	-0.282
Sweden	-0.404	-0.395	-0.294	-0.221	-0.292
United Kingdom	-0.516	-0.410	-0.354	-0.267	-0.256

Table 5.13: Average industry collusiveness

Country	1998	1999	2000	2001	2002
Austria	0.289	0.037	0.037	0.037	0.037
Belgium	0.314	0.062	0.062	0.062	0.062
Denmark	-0.136	-0.136	-0.136	-0.136	-0.343
Finland	-0.318	-0.318	-0.318	-0.318	-0.318
France	0.658	0.407	0.407	0.407	0.407
Germany	0.742	0.491	0.491	0.491	0.491
Greece	0.542	0.542	0.542	0.542	0.290
Ireland	0.549	0.549	0.298	0.298	0.298
Italy	0.436	0.184	0.184	0.184	0.184
Luxembourg	0.123	-0.128	-0.128	-0.128	-0.128
Netherlands	1.011	0.760	0.553	0.553	0.553
Portugal	1.009	1.009	1.009	0.757	0.757
Spain	0.666	0.666	0.414	0.207	0.207
Sweden	0.073	0.073	0.073	0.073	-0.133
United Kingdom	0.414	0.414	0.207	0.207	0.207

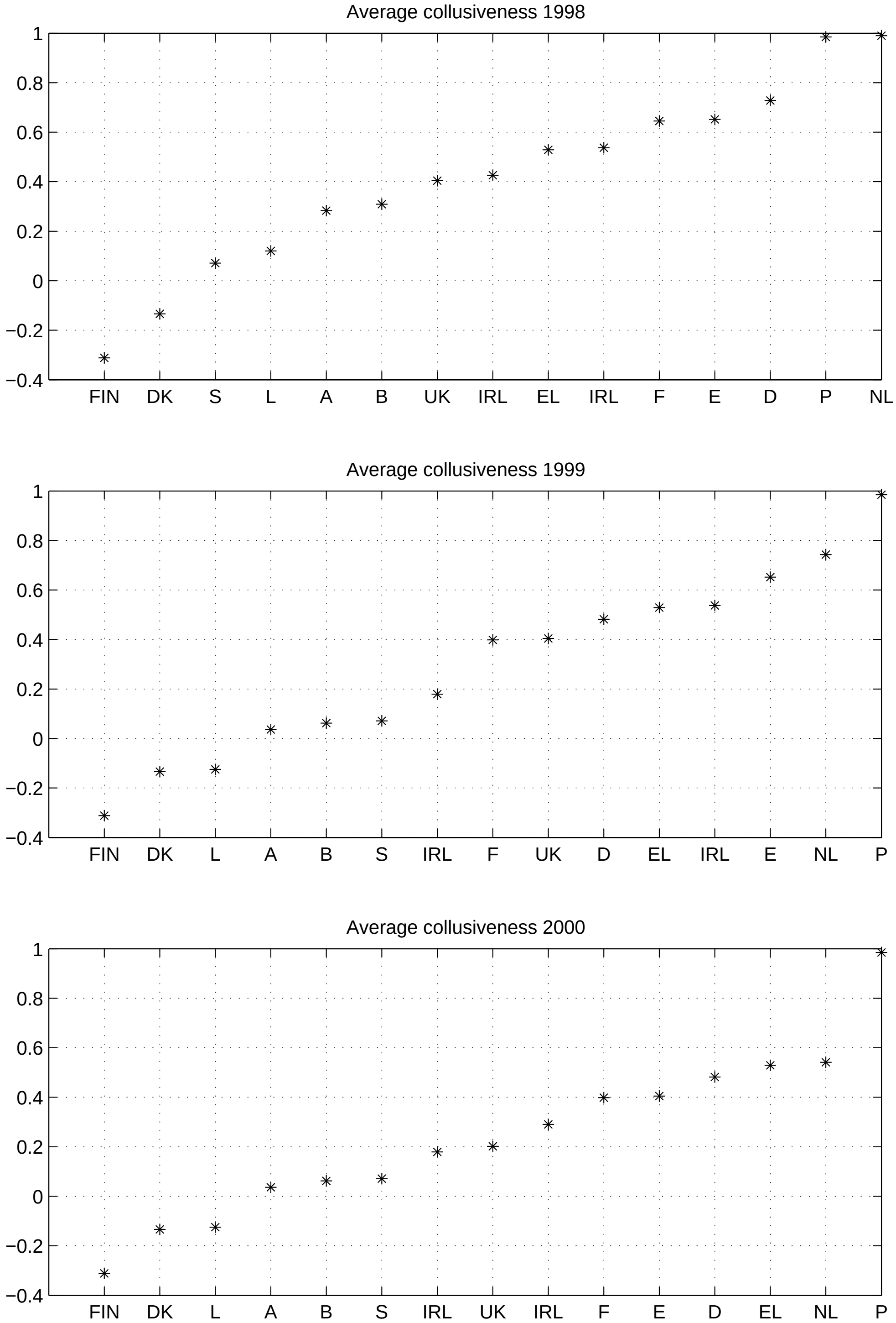
Table 5.14: Average industry marginal costs in $US PPP

Country	1998	1999	2000	2001	2002
Austria	37.11	33.76	32.70	32.35	30.27
Belgium	39.45	36.22	34.71	33.68	31.23
Denmark	36.71	33.59	32.46	31.34	29.24
Finland	37.23	32.79	31.63	30.91	29.21
France	33.07	29.16	28.47	28.56	27.20
Germany	40.11	36.10	34.43	33.40	31.21
Greece	44.13	38.63	30.48	27.54	24.56
Ireland	34.01	27.82	26.65	26.69	25.04
Italy	39.98	32.13	30.38	30.03	28.19
Luxembourg	33.89	31.51	30.63	30.02	27.94
Netherlands	37.32	33.92	33.04	31.41	29.24
Portugal	28.61	23.18	22.23	23.47	21.85
Spain	34.46	28.77	27.57	27.43	25.82
Sweden	37.96	32.07	31.16	29.61	27.40
United Kingdom	37.89	32.20	30.27	27.72	25.78

Table 5.15: Average industry markup estimates in $US PPP

Country	1998	1999	2000	2001	2002
Austria	9.15	4.46	7.22	7.63	8.92
Belgium	4.90	3.88	5.85	3.30	6.31
Denmark	-9.05	-6.47	-2.40	-5.91	2.48
Finland	-12.62	-10.10	-10.06	-9.36	-7.41
France	17.34	19.50	21.10	11.10	8.86
Germany	47.26	8.29	10.45	1.23	3.05
Greece	18.77	23.35	28.34	22.05	17.13
Ireland	30.45	35.10	17.83	11.94	4.13
Italy	29.20	7.82	14.85	15.18	3.85
Luxembourg	13.37	0.09	-1.74	-8.73	-8.23
Netherlands	69.77	15.14	7.31	1.09	10.24
Portugal	53.79	43.10	44.01	40.80	24.07
Spain	38.79	20.83	30.66	11.82	5.51
Sweden	7.01	11.86	1.51	-4.98	5.08
United Kingdom	19.49	13.44	9.07	2.00	2.75

Figure 5.2:


Average collusiveness 1998
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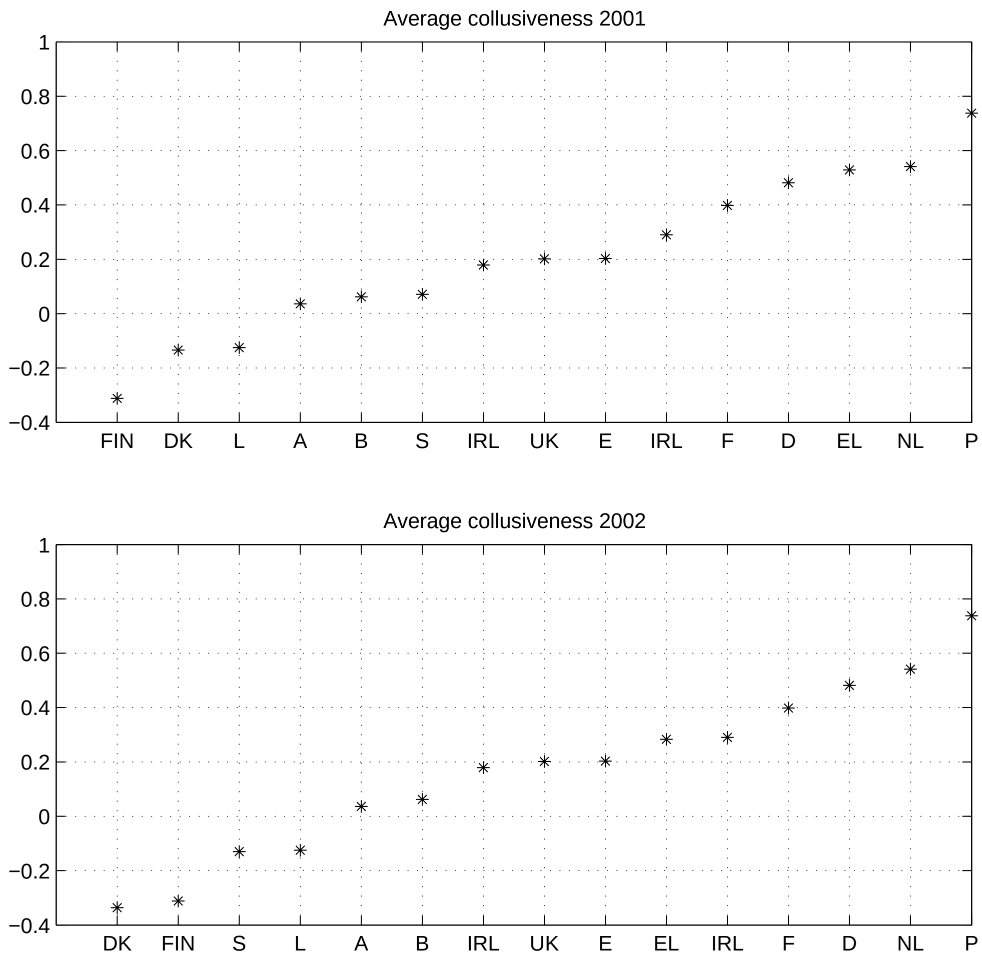
0.8
0.6
0.4
0.2
0
−0.2
−0.4
FIN DK S L A B UK IRL EL IRL F E D P NL
Average collusiveness 1999
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
FIN DK L A B S IRL F UK D EL IRL E NL P
Average collusiveness 2000
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
FIN DK L A B S IRL UK IRL F E D EL NL P

Figure 5.3:


Average collusiveness 2001
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
FIN DK L A B S IRL UK E IRL F D EL NL P
Average collusiveness 2002
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
DK FIN S L A B IRL UK E EL IRL F D NL P

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