Topics in the Industrial Organization of Electricity Markets

Jon Thor Sturluson

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To Anna

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No one is an island.

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Reykjavik, April 2003
Jon Thor Sturluson

Contents

Summary

This dissertation consists of four essays, all related to the field of Industrial Organization of electricity markets, in one way or another. It is far from being a concise overview of the field, but rather eclectic bits and pieces of a greater puzzle that's being studied by a large group of people.

The first three essays deal with issues concerning retail markets for electricity and similar goods. The first one is an empirical study and the other two apply game theory. The fourth essay is different in many respects, primarily methodologically, as it reports a laboratory experiment on a classical theme in Industrial Organization: price competition with capacity precommitment. Even though this final essay is more general than the rest, it is still relevant for electricity markets as it concerns the validity of models often used to analyze competition of electricity market.

Chapter 1

The first essay tries to explain the coexistence of three characteristics of the Swedish retail electricity market: It concerns a homogenous product, while price dispersion is high and consumers are reluctant to switch from incumbent suppliers to rivals. Consumers' reluctance to switch, as in this case, is usually explained either by search costs or switching costs, or even both. The purpose of the paper is to evaluate the relative importance of these two factors and study their interplay. The sequential choice problem facing consumers, a) whether to become an active searcher or not, and b) whether to switch suppliers or not, is modeled as two consecutive discrete choice problems and estimated using Swedish data.

I find that switching costs are, on average, larger than search costs. Yet, search costs are important for it appears that users of electricity must become active consumer before they respond to changes in switching costs to any degree.

Various forms of passive information such as direct marketing and word-of-mouth, encourage active searching.

Chapter 2

Essay 2 develops a simple model of a asymmetric price duopoly, where one firm is an incumbent with an established relationship to all consumers, while the other firm is a new entrant in the market. Consumers have different consumption levels and can face a switching cost or a search cost. Retail electricity markets are the prime example. Given conditions on the distribution of these costs, an asymmetric equilibrium in prices exists. In equilibrium, the rate of switching can be a bad measure of market performance. A decrease in switching costs affects prices for the benefit of all consumers and not only those who choose to switch. A decrease in search costs is likely to be primarily in the interest of those consumers that do not wish to search. This suggests that consumers may be facing a free-rider problem, discouraging search as well as switching.

Chapter 3

In the third essay, Niclas Damsgaard and I consider an important policy issue concerning vertically integrated firms in network industries. An incumbent firm provides regulated local network services while being active in the deregulated but imperfectly competitive retail market. Its total costs are known, both to the regulator and its competitor, while the distribution between the two services is private knowledge of the incumbent. The firm has a natural incentive to overstate its costs for the network services to receive a higher regulated price. However, since total costs of both operations are known, a claim of high network costs signals low retail costs. When firms compete in prices, which are strategic compliments, the integrated firm would like its competitor to belief that retail costs are high as well. The regulator, through a combination of price incentives and monitoring, can utilize this trade-off and induce an information-revealing separating equilibrium in which the incumbent claims its true type. The optimal combination of price incentives and monitoring and the conditions under which such a separating equilibrium is preferred to a pooling equilibrium are derived.

Chapter 4

The fourth essay, co-authored by Chloé Le Coq, investigates why subjects in laboratory experiments on capacity constrained price competition seem to consistently choose capacity above the Cournot level - the subgame-perfect equilibrium. We argue that this puzzling regularity may be attributed to players perceptions about their opponents skill or level of rationality. In our experimental design we used the level of experience (number of periods played) as a proxy for the level of rationality and matched subjects with different levels of experience. We found evidence of capacity choices being decreasing and prices increasing with opponent's experience. This suggests that if subjects have a tendency to underestimate the rationality of their opponents, or that rationality is actually limited for a large proportion of subjects, the observed regularity need not be a puzzle after all.

Chapter 1

Consumer Search and Switching Costs in Electricity Retailing

Consumer Search and Switching Costs in Electricity Retailing*

Jon Thor Sturluson

Abstract

Three important characteristics of the Swedish retail electricity market: homogenous product, considerable price dispersion and low rate of switching from incumbent suppliers to rivals, are a cause of concern for competition policy. Consumer's reluctance to switch , as in this case, is usually explained either by search costs or switching costs, or even both. To evaluate the relative importance of these two factors the choices to, a) become an active searcher, and b) switch suppliers, are modelled as two consecutive discrete choice problems and estimated using Swedish data. We find that switching costs are, on average, larger than search costs. Yet, search costs are important, for it appears that a great majority of users of electricity need to be active consumer if they are to respond to changes in switching costs. Various forms of passive information such as direct marketing and word-of-mouth, encourage active searching.

*Several people have contributed to this paper with constructive comments on earlier stages. Among those are: Sveinn Agnarsson, Niclas Damsgaard, Magnus Johannesson, Chloé Le Coq, Richard Green, Mårten Palme and Søren Leth Pedersen. I would also like to thank participants in seminars at the Stockholm School of Economics, Institute of Economic Studies and on two occations within the Nordic Energy Research Program. A few people at the Swedish National Audit Office, where I obtained the data, deserve a fair share of thanks, especially Anders Berg. Last but not least, I thank my supervisor, Lars Bergman for his guidance. The project was financed by the Nordic Energy Research Program.

1 Introduction

In this new age of information consumers are constantly facing an increasing number of complicated choices. A surge in public use of information technology has lead to an incredible expansion of product information through advertising, direct marketing and new market mechanisms. At the same time, increased liberalization has created new markets where exchange was previously regulated, giving consumers opportunities to choose from a larger variety of products and suppliers. Important examples from the last decade are telecommunication services and energy, i.e., electricity and gas.

Persistence in consumer choice is an important feature of many such markets and is observed in the low rate of switching from incumbent suppliers, such as pre-deregulation monopolists, to alternative rival service providers. True enough, the rate of switching can be a misleading indicator of market performance or competitiveness. It need not be a manifestation of market power. Consumers have, for instance, little reason to switch if markets are very competitive and price dispersion low. Moreover, even if prices differ considerably between suppliers and brands, alarm bells should not go off automatically if product attributes other than price are important. Nevertheless, we can find clear examples of markets for fairly *homogenous goods* with *low rate of consumer switching* and *high price dispersion.* In such cases it is doubtful that competition is working as it is supposed to; for the benefit of consumers. Here we take a look at one such market where these three characteristics coexist - the retail electricity market in Sweden.

From the perspective of a household consumer electricity is almost as homogenous as a good can be. Consumers receive electric power via a distribution network which is interconnected with several other distribution networks and a number of suppliers, via a transmission grid. Electricity "flows" through these networks according to basic laws of physics, and nobody can say exactly where the power being used originates. Hence if a particular household switches suppliers, the physical quality of its power supply is unaltered.[1] One could object to this view on the grounds that many different contract alternatives are available to the consumer. Contracts can differ in a variety of ways, e.g., price schedules, duration, and interruptability. In some cases consumers are even offered pay a premium in exchange for a guaranteed

[1] The flow of electrons in the transmission and distribution systems is altered for all users, but negligibly so, and not more for the consumer in question than anyone else.

share of renewable energy generation. But since most Swedish electricity suppliers offer a similar range of contracts, it is hard to argue that there is any real product differentiation.

The concept of consumer switching costs or substitution costs, as originally phrased by Weizsäcker (1984), is a broad synonym for many different forms of disutility consumers incur when switching between suppliers or brands. Switching costs can be tangible costs like explicit administration fees or, in the case of electricity, the cost of installing modern metering equipment. However, the dislike to establish new business relationships, a distrust for new things and lost emotional ties with a reliable brand, can also translate into switching costs.[2] Klemperer (1987*a*, 1987*b*) and Farrell & Shapiro (1988) have used this concept to analyze its implications for market equilibrium and dynamics, including market power issues. In this paper we will only consider its importance in relation to consumer behavior, therefore taking firms' actions as given.

The low level of switching as well as switching patterns and price dispersion, suggest that switching costs are important in the retail electricity market. The rate of switching is for instance, considerably higher for larger households than smaller, while the difference between the highest and the lowest price is as much as 40 to 50 percent.[3] Typically large incumbents' prices are higher than small firms' on all forms of contracts. Furthermore, due to non-linear pricing, the difference is greater for small scale users.

But even though the switching cost story is consistent with stylized facts, other explanations may play a significant role. Consumers' persistence to stay with incumbent suppliers can also stem from a limited interest in acquiring the relevant information to make a switch. This lack of interest can of course be rational in it self if the cost of acquiring information of sufficient quality exceeds the expected gains of switching. Search costs have been considered as a key explanatory factor for price dispersion, at least since Stigler (1961) in various choice based problems, such as Dahlby and West (1986) in the case of automobile insurance. Their results support the equilibrium price dispersion prediction as a result of search costs, developed by Carlson and McAfee (1983).

[2]See Klemperer (1995) for a detailed definition.

[3]See for instance the Swedish Consumer Agency's official price comparison website: http://www.elpriser.konsumentverket.se/. To give an example, the price of a one year fixed contract to households with annual consumption of 20,000 kWh ranged from from SEK 13,695 to 19,657 in February 2003.

A priori, both these costs seem important. The subject of this study is to analyze if consumer behavior can be attributed to these two types of costs and how these costs are distributed across households. The purpose is to shed some light on the causes of observed consumer persistence in this particular market in the hope that a better understanding of consumer behavior will prove to be useful for policy analysis regarding the future prospects of electricity retailing. Relevant policy issues include: switching subsidies, e.g., using shopping credits; promotion of price transparency; and regulation of default contracts. Joskow (2000) has even raised the question if retail markets are needed altogether, since the persistence problems seem to outweigh the value-added created by retailers. This opinion is not universally accepted, though, and has been attacked by Littlechild (2000) among others. The distribution of these costs can have fundamental effects on retailers pricing strategies, as studied in detail in chapter 2, which turn out to be important for any policy implications. Thus, we postpone further discussion on the subject until later.

In a related paper Schlesinger and der Schulenburg (1999) study the effects of information on switching behavior in the market for compulsory car insurance in Germany, using survey data. They find that informedness plays a key role in switching decisions, a feature that according to the results presented in this paper, also turns out to be important for the Swedish electricity market. Moshkin and Shachar (2000) study switching behavior of American television viewers based on data of actual switches between channels. Their approach is novel but limited, as they aggregate consumers into two distinct groups; those who are constrained by search costs on the one hand, and those constrained by switching costs on the other. Both costs seem to be important even though a larger proportion of consumers' reluctance to switch channels stems from switching costs. Giulietti, Waddams-Price and Waterson (2001) study search and switching costs in the UK gas market based on survey data. They find variables associated with search costs to be statistically more significant than those associated with switching costs in explaining consumer reluctancy to switch. Based on these findings, they propose that policies aimed at reducing search costs should be emphasized.

This papers supports earlier results; that both search costs and switching costs are important determinants of consumer behavior. However, while divergence in search costs is easier to explain by observed variables than divergence in switching costs, the aggregate level of switching costs, including the unexplained part, is much larger than search costs on average. Still, search costs are more important than might be thought at first. We find that active consumer participation is a prerequisite for active response to price competition. But passivity can be the result of switching costs as well as search costs, for the expected benefit of searching must cover both search- and switching costs if the consumer is to find it worth while to become, and stay, active in the market.

The remainder of this paper is structured as follows. In the following section we start of by describing the basic model for qualitative choice of search and switching. Section 3 provides some background on the Swedish retail electricity market and describes the data used in the study. In section 4 we go into more detail about the expected monetary gains from switching electricity suppliers compared with switching costs. An econometric model of switching choice, conditional on search behavior, is reported in section 5. Section 6 discusses the choice to search actively for available alternatives and the estimated search cost function. Before we conclude, with section 8, we consider the impact of changes in search- and switching costs on consumer policy.

2 The basic model

Consider a single decision unit's problem of choosing electricity suppliers. In the following we refer to this unit (or household) as the consumer. We will assume that the consumer is risk-neutral and maximizes his expected utility. His choice problem is two-dimensional and dichotomous. First, he chooses whether to collect information about available service alternatives and their costs. Second, he chooses whether to stay with the incumbent electricity supplier or switch to the rival supplier offering the lowest price. Obviously this involves considerable aggregation of alternatives. It is arbitrary to say that investment in information is a binary choice. In real life it is better described as a continuous process, so that the choice is more in terms of equating the marginal benefit of additional search to its marginal cost. In a different setting it can be viewed as a discrete sequential process (Stahl 1989). Assuming a binary choice structure is by no means favorable in general. It is only in this specific context that we find it satisfactory. Active search, e.g., using the internet to compare prices, usually reveals the cheapest alternative fairly quickly while store-to-store wandering, which is the typical allegory in most search-theory models, is not particularly relevant. In formal terms this amounts to assuming that search involves large fixed costs relative to variable costs. This assumption, together with the homogeneity assumption, makes the identity of the rival supplier switched to unimportant. Another important simplification is the abstraction from the effect of time. We will discuss how time can affect the outcome of this static framework in section 8

The expected monetary gain from switching suppliers is a random variable, both from the perspective of the researcher and the consumer himself. Even if a consumer has complete information about prices, his use of electricity in any given period is essentially random. After all, demand for electricity is derived from different needs like for heating, lighting and appliance use. The consumer's true gain from switching, which is not observable ex ante, is the random variable τ with the prior probability density function f^p. The superscript p can also stand for *passive* as a passive consumer's information set is also his prior. The consumer can choose to search actively for information about different offers and become an *active* consumer. As the consumer finds more offers to choose from his probability density function becomes f^a. To simplify notation let us denote the consumers prior and posterior expected gains as $\gamma^p = \int_{-\infty}^{\infty} \tau f^p(\tau)\, d\tau$ and $\gamma^a = \int_{-\infty}^{\infty} \tau f^a(\tau)\, d\tau$.

A working hypothesis is that the expected gain from switching increases with search, or that $\gamma^a > \gamma^p$. This property should appear naturally as search gives the consumer a larger set of prices to choose from. The direct gain from taking the cheapest available offer is naturally non-decreasing as the set of offers expands. A second hypothesis is that the standard deviation of the expected gain, decreases with search. This can be expected if active search improves the consumer's prediction of how much electricity he will consume in the relevant contract period and his general understanding of how the market works. Below we will look at how well these hypothesis fit with our data.

The consumer tackles the twofold choice problem sequentially. To begin with, he considers if he should perform active search and then, given his current information, he chooses whether to switch or not. The decision making process and the four possible outcomes are illustrated in figure 1. We consider the decision process in the reverse order. First, conditional on being either active or passive, the consumer compares his expected gain, whether it is γ^a or γ^p, with his switching cost ω, and switches suppliers if

$$\gamma^j - \omega > 0, \tag{1}$$

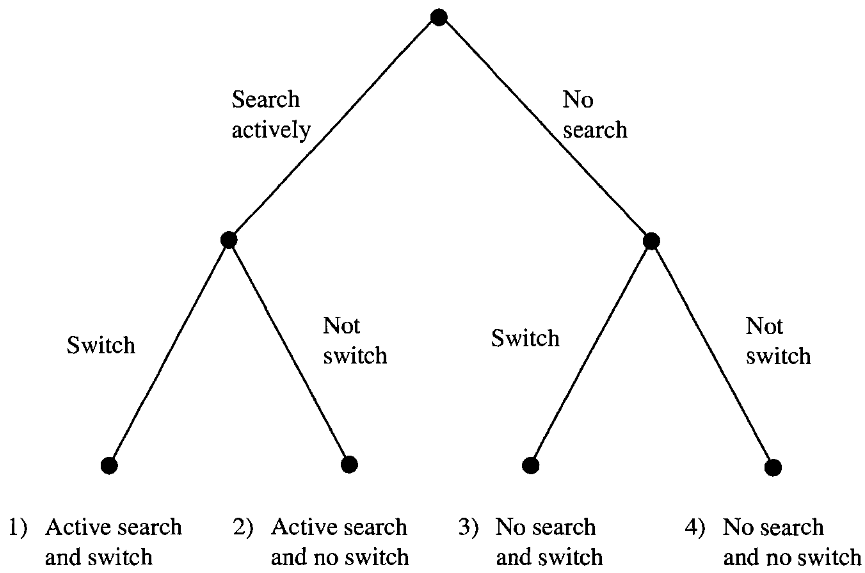

Figure 1: The structure of the consumers decision problem

where $j \in \{p, a\}$. Both terms in (1) are individual specific, even though subscripts are skipped to simplify notation. Second, the decision whether to search actively for information or stay a passive consumer involves a similar comparison of benefits and costs. If the benefit exceeds the cost of searching, the consumer prefers to search - to become an active consumer. The benefit of searching depends essentially on the difference of expected gains from switching given different information levels. Hence, we prefer to postpone discussing it in detail until section 7, after we have analyzed gains from switching.

3 Electricity retailing in Sweden

3.1 Overview

Swedish households have been free to choose electricity suppliers since 1996, but prior to November 1999 all households where required to purchase a new sophisticated meter, which could measure the time of use, in order to switch suppliers. Traditional meters only allow manual readings, which are done annually, and cannot discriminate between use in peek and off-peak hours. Revoking this requirement while adopting average-load schedules to approximate the time of use for consumers with old meters, is believed to have lead to a sharp reduction in switching costs. In a competitive wholesale market where prices are determined for each and every hour of the year, average-load scheduling can be quite inefficient. If the wholesale market is sufficiently competitive, price should reflect the relevant marginal (real or opportunity) cost of power generation at each point in time. A Consumer whose power bill is based on average-load scheduling has no incentive to respond to short-run fluctuations in prices, thereby increasing the difficulty of balancing supply and demand through the market mechanism. How severe the resulting inefficiency is depends on the scale of the price fluctuations and the cost of alternative means of short-run balancing. Despite the adoption of average-load scheduling in Sweden, more and more advanced meters are being installed, primarily on the initiative and expense of power companies. The installment cost[4] is believed to be smaller than the value of more detailed information on consumption patterns of relatively large users and the potential gain from time-of-use contracts.

The vast majority of Swedish households are subjected to the average-load scheduling scheme. Despite aforementioned problems, it has the clear advantage of eliminating almost all physical switching costs and at the same time homogenizes electricity contracts. Most electricity suppliers offer three types of contracts to small businesses and households. First of all, a contract with a variable price which is usually calculated as the monthly average of the Nordpool spot-market price plus a predetermined markup.[5] Such a contract is sometimes supplemented with a price ceiling (the equivalent of a call option). The second, is a fixed price contract with one, two or three year duration. The price per kWh stated in such contracts is usually in line with the market price of forward contracts with similar duration. The third type, and still the most significant one in terms of number of subscribers, is the default contract. A default contract is based on a standard rate with conditions similar to those of the pre-deregulation regime. In practice the price for electricity under such a contract is relatively stable but can be changed after a formal announcement made well in advance. Default contracts are not explicitly regulated but are scrutinized by the Energy Administration. Changes in the de-

[4]Depending on the chosen technology the cost can be in the range SEK 2000 - 10 000.

[5]The fact that only a small proportion of homes have an advanced time-of-use meter implies that most consumers pay an average price over the month based on an aggregate load curve.

fault price are infrequent and usually occur in relation to significant changes in the wholesale price. While the level of variability of prices is somewhere in between the variable and fixed price contracts, the average price is significantly higher in the case of default contracts.

3.2 Data

To explore consumer behavior in this market we use data from a questionnaire conducted by the Statistics Sweden in February and March 2000 on behalf of the Swedish National Audit Office (Riksrevisionsverket 2000). Representatives of 986 households, from a random sample of 1400, were interviewed about their choices regarding the electricity market. In addition to questions directly linked to behavior and views regarding the choice of electricity suppliers, subjects were asked about several background factors, such as gender, age, income and place of residence. Unfortunately an important variable, education attainment, was left out by mistake. A second mistake in the preparation of the questionnaire turned out to be rather useful for the present analysis. Response alternatives for expected annual gains from switching where rather badly scaled in the original questionnaire. Supplementary interviews were held, where the same question was repeated, but with more appropriate scaling. Even though the net return to the second survey was somewhat smaller then the original one, it is convenient for the present study to use both set of answers to get more variability of answers in this key variable.

Apart from generally assessing the result of the named reform, the purpose of the questionnaire was to investigate consumer attitude towards the reform and how various governmental agencies had affected behavior or views. Hence, many of the variables gathered are of little interest for this paper. Those which are however, will be explained in context below.

Using questionnaire data has both advantages and disadvantages. A clear advantage is that the survey gives a good picture of the consumer's subjective evaluation of the benefits associated with switching. A drawback to it is that since the questionnaire was performed ex post, it is difficult to determine if it is the hope for large gains that drives switching or if it is the actual realized gains after switching that are reported. In addition there might be a problem of cognitive dissonance (Festinger 1957), where people adjust their perceptions to fit to their actions, rather than the opposite.

Table 1: Savings by passive consumers when renegotiating with current supplier or switching suppliers

	Savings from renegotiating contract		Savings from switching suppliers	
	SEK per year	Percent	SEK per year	Percent
a) 3500 kWh per year (e.g., a 3 room apartment with district heating)				
Hemel (Stockholm)	224	23%	513	53%
Vattenfall	264	28%	503	53%
Sydkraft (Malmö area)	154	17%	467	51%
Plusenergi (Gothenburg)	217	23%	474	51%
Graninge	123	14%	418	48%
b) 20.000 kWh per year (e.g., detached housing with electric heating)				
Hemel (Stockholm)	1 428	30%	2 196	46%
Vattenfall	1 764	35%	2 416	48%
Sydkraft (Malmö area)	880	20%	1 770	41%
Plusenergi (Gothenburg)	1 240	26%	2 140	45%
Graninge	940	22%	1 680	39%

Source: Own calculations based on data collected by Montel.
http://www.montel.no/enduser/enduserprice.htm

A passive consumer, with a default contract with one of the larger incumbent suppliers, could reap considerable gains by switching suppliers or renegotiating with his current supplier in March 2000, when the survey was conducted. As listed in table 1 a typical electricity bill, excluding network tariffs and taxes, could be reduced by 39 to 53 percent depending on supply area and level of consumption. By signing a one year fixed price contract with the current supplier a typical consumer could reduce his bill by 14 to 35 percent. In both cases we assume that the consumer has a default contract before switching or renegotiating and that when switching they go to the cheapest alternative supplier. Note that the default contract price changes from time to time, reflecting long-term changes in wholesale prices but not regular seasonal price fluctuations. Consequently a fixed price contract should be more attractive then a default contract for a risk neutral or a risk averse consumer, assuming equal average prices. There can also be a value associated with being able to leave the default contract at any future date. The net outcome of these two effects is likely to be small, relative to a one year contract, and cannot explain the magnitude of the average price difference between these two contract forms.

The gains from switching are, in relative terms, greater for small users than large

Table 2: Share of households that have switched electricity supplyers by March 2000

	Have switched (%)	Attempted to renegotiate (%)
a) *Full sample*	10	11
b) By *perceived annual power bill*		
<1500	3	4
1501-3000	5	3
3001-6000	10	8
6001-10000	6	17
10001-20000	14	20
>20000	22	29
c) By expected annual gain from switching		
<250	9	-
251-500	11	-
501-1000	17	-
1001-2000	24	-
>2000	40	-

Source: Riksrevisionsverket (2000)

users while it is more attractive for large users to renegotiate their contract with the incumbent supplier than it is for small users. This stems from the fact that large incumbents typically apply two part tariffs while the cheapest rival suppliers offer flat tariffs, and for small users the fixed part of the tariff is quite a significant part of the overall electricity expenditure. Table 1 also suggests, that gains from switching increase with the size of suppliers' regional market. This pattern is verified in a more comprehensive comparison of profit margins in ECON (2001). Profit margins of large suppliers (with more than 75,000 customers) were for instance 1.8 öre per kWh higher than small suppliers' (less then 25,000 customers) margins, on average in the period from August 1999 to July 2000. Vertically integrated companies with own generation had margins 2.1 öre per kWh above the levels of independent electricity retailers on average in the same period.

In comparison to these significant savings available to households, the rate of switching has been remarkably low. Table 2 shows the main results of the questionnaire: only 10% of households had switched suppliers by March 2000 and 11 % had attempted to renegotiate with their current supplier by that time. The shares differ considerably depending on the size of the electricity bill (as perceived by the household representative). Among households who perceive their bill to be above SEK 20.000 per year, the measured rate of switching is 22% while only 3% of households with electricity costs lower then SEK 1,500 had switched, according to the survey. The tendency to renegotiate has a similar pattern. What seems to be an even more important determinant of switching is the expected annual gain from switching. Among households with low expected gains the rate of switching is low while as much as 40% of households who expect their gain to be at least SEK 2.000 per year had switched by the time the survey was conducted.

The share of households that have switched or renegotiated has grown since survey was conduced in early 2000. A more recent survey conducted by TEMO on behalf of Svensk Energi, in April 2002, indicates that about 19% of Swedish households have switched suppliers (at least once) by this time while 18% have renegotiated. While these two surveys are not perfectly compatible, comparison with earlier TEMO surveys shows a clear trend in the direction of increased switching and renegotiating.

4 Gains from switching

The first step is to take a closer look at the expected gain of switching from the incumbent supplier to a rival, as perceived by consumers. Assume that the actual annual gain from switching, γ^j, is a random variable, linearly separable in a deterministic and a stochastic part,

$$\gamma^j = g^j + \varepsilon^j,$$

where $j \in [a, p]$ as before. The error term ε^j includes both individual uncertainty about gains as well as measurement errors.

The survey does not provide us with actual gains from switching. We do however know what the respondents claim to believe their annual gains are. The claims are not used as direct proxies for perceived gains for two reasons. First, even though a strong positive relationship between the expected gains and the act of switching can be expected, there might not be a one-way causal relationship at work. Individuals expecting large gains are likely to be more eager to switch suppliers. But consumers who have already switched might overestimate their gains while those who have not switched might underestimate theirs. It is quite possible that when new information arrives that contradicts previous beliefs, a person may react by interpreting the new information in such a way that conforms with previous information or actions (Festinger 1957). The second reason is that a significant share of respondents were not willing or able to express their expected annual gains. It is highly unlikely that this stems from concerns for privacy, as other more intimate personal questions were answered in almost all of these cases. What seems to be the culprit is that the respondents have not taken the time and effort to think about the issue enough to be able to state their estimates with confidence.

In order to allow for these problems we, as a first step, estimate an expected annual gains function using only exogenous explanatory variables. This can be viewed as the first step in a two-stage estimation process. The following equation is estimated using maximum likelihood, taking into account non-random sample selection, following Heckman (1979) and Greene (1981).[6]:

$$\begin{aligned}\widetilde{g} &= \beta_0 + \beta_{H_1} \times H_1 + \beta_{H_8} \times H_8 + \beta_{H_9} \times H_9 + \beta_{rn} \times RN \\ &\quad + \beta_{c_1} \times C_1 + \beta_{c_2} \times C_2 + \beta_{c_3} \times C_3 + \beta_{c_4} \times C_4 + \beta_{c_5} \times C_5 + \beta_{c_6} \times C_6 \\ &\quad + \beta_{ac_1} \times C_1 \times A + \beta_{ac_2} \times C_2 \times A + \beta_{ac_3} \times C_3 \times A \\ &\quad + \beta_{ac_4} \times C_4 \times A + \beta_{ac_5} \times C_{i5} \times A + \beta_{ac_6} \times C_{i6} \times A + \alpha\widehat{\lambda} + \varepsilon_{\widetilde{a}}. \end{aligned} \tag{2}$$

Since we can only observe g^a or g^p for each observation we let $\widetilde{g}$ be the expected annual gains for the respective consumer's search choice. All variables on the right hand side of 2 are dummy variables, except $\widehat{\lambda}$ which is the estimated inverse Mill's ratio. H_k are location dummies where $k = 1$ refers to Stockholm, $k = 8$ to the Gothenburg region and $k = 9$ to the Malmö/Lund region. Each of these regions has a single incumbent supplier and the variables are primarily included to pick up the slight variation in the incumbents pricing strategies in different supply regions. The rest of the country serves as a benchmark. RN is a dummy variable taking the value 1 if the consumer in question has renegotiated his contract with his incumbent supplier. C_l are dummies representing the discrete choice alternatives of expected electricity expenditure, e.g., a consumer with very low expected expenditure has $C_1 = 1$ while others have $C_l = 0$. A consumer with high expected expenditure has

[6] Dummy variables for gender, income levels (three income groups) and different channels which passive information can reach the consumer, are included as independent variables in the the sample selection probit model.

$C_6 = 1$. The benchmark consists of consumers who are unable to place themselves in any of the categories. A is a dummy variable taking the value 1 if a consumer has performed an active search and 0 otherwise. An active search is primarily linked to better information about the distribution of prices. This justifies using cross terms between active search and expected expenditure.

The parameter estimates for α and β's are not of direct concern here. We are only interested in using (2) to make projections for the whole sample, conditional on search about expected annual gains. Let $\widehat{g}^a$ be prediction of $\widetilde{g}$ using the estimated parameters and restricting $A_i = 1$ and $\widehat{g}^p$ the conditional prediction when $A = 0$. This gives us estimates of expected annual gains from switching, with and without active search, for the whole sample. The predictions, which descriptive statistics are shown in table 5, are roughly of the same order as the examples shown in table 1 which suggest the absence of a particular bias in consumers expectations of gains from switching. Furthermore, the parameter estimates suggest that consumers in Stockholm expect larger gains than consumers in Gothenburg, which in turn see more gains from switching on average than consumers in Malmö/Lund. This is qualitatively consistent with the pattern in table 1 but is not statistically significant. Finally, the cross-terms including the variable A are jointly significant at the 5% level of significance, and independently for the two highest income groups. The signs of these parameters are consistent with the hypothesis that an active search increases the expected benefit of switching.

5 Switching costs

Switching costs can be classified into two categories, as *informational* switching costs and *transactional* switching costs (Nilssen 1992). The defining feature is that, while informational switching costs are only incurred when a consumer makes an initial switch between suppliers, transactional switching costs are incurred for every switch made. The former kind, which we emphasize here, can stem from various factors including: lack of trust for rival suppliers and emotional ties with the incumbent. In a case like this one, when all consumers start out in a "relationship" with an incumbent supplier it can be difficult to discern informational switching costs from brand preferences or other forms of vertical product differentiation. We do not make any attempt to distinguish between these two preference components and focus on the switching costs terminology. Consequently, a part of what we here label as switching costs could, by all right, be just as well labeled as vertical product differentiation. This should not have any consequences for the analysis, as long as we can trust that transactional switching costs are minimal.[7]

Direct observations of switching costs are not available and we can only approximate them through estimation. As in the case of expected gains we assume that the aggregate cost of switching is a random variable. Furthermore that it is linearly separable in a deterministic term, which is a linear function of observable exogenous variables, and a zero mean random term. More specifically

$$\omega = \mathbf{x}'\boldsymbol{\beta}_{\omega} + \varepsilon_{\omega},$$

where $\mathbf{x}$ is a vector of explanatory variables and $\boldsymbol{\beta}_{\omega}$ the associated parameter vector. Several variables that were gathered in the survey are potentially important. We can not, however, include any of the variables used to estimate the expected gain, such as regional dummies. Doing so would clearly lead to multicollinearity. For similar reasons we can not use variables that are strongly correlated with the expected gains, such as a dummy for electric heating and form of housing. In addition we reject any variables that are particularly subjective, such as results from questions about how easily consumers can compare offers (on the scale one to four) and how well they understand the structure of their electricity bill, i.e., energy, distribution and tax components. Apart from being extremely subjective, the causal relationship between these scores and switching suppliers is questionable because the process of switching reveals the separation of the network and energy tariff. After all, consumers who switch receive two separate bills; one for the network service and one for their purchase of energy.

We are left with a set of variables, all dummy variables, that are undoubtedly exogenous to the supplier choice. At the same time all of these might potentially affect switching costs. These variables are described in Table 3 together with the

[7] Market studies, estimating consumer's willingness to pay for different attributes of electricity, e.g., Goett, Hudson & Train (2000) using hypothetical conjoint-type experiments with Californian consumers, suggest that two attributes of electric power are most important: the price and the the supplier profile. This suggests that consumers are willing to pay for keeping the incumbent supplier rather than a less-well-known rival. Since most suppliers in the Swedish market offer a similar range of attributes apart from what is embedded in the firm profile, our approach of treating electricity as a homogenous good while allowing for switching costs when consumers switch from an incumbent to a rival, seems warranted.

Table 3: Variables of the switching cost function

Variable	*Description (variable takes the value of 1 if...)*	$P(1)$
MALE	Respondent is male, alternatively female.	.57
AGE1	Respondent is between 40-59 years old .	.46
AGE2	Respondent is 60 years or older.	.26
INC1	Highest income in household between SEK 16.000 and 23.000 a month.	.40
INC2	Highest income in household higher than 23.000 a month.	.26
INTNET	Respondent has access to the internet, either at home or at work or both.	.64
ADPAP	Respondent remembers specific advertisements from printed press.	.73
ADTV	Respondent remembers specific advertisements from television.	.68
ADDIR	Respondent been exposed to direct mail advertising.	.83
ARTIC	Respondent has read newspaper article(s) about the reform.	.70
OINFO	Respondent has received information by other means, e.g., from friends or colleagues.	.14

frequency of ones in the whole sample. The number of usable observations is 878 for all of these, except the income variables, which only have 867 responses. As a consequence the regressions below will be based on the restricted sample of 867. In the case of the age and income variables, where respondents are divided into three groups, the youngest age and lowest income groups form the benchmark embedded in the constant term.

Gender and age are general classifying variables that might or might not have explanatory power over switching costs. The surveyors asked if they could speak to that person in the household that usually made decisions about the purchase of electricity or alternatively the person who normally paid the electricity bill. Income is potentially important, but not in any clear way. In the absence of data on education, it might be taken as a proxy for human capital, and if individuals with more human capital are more likely to understand the problem at hand, there might be a positive effect from the income dummies. It is however difficult to rule out the possibility that income is a proxy for time value which is expected to affect the cost of switching positively.

6 Switching choice

The model for switching choice is a standard dichotomous probit model, well documented in Amemiya (1981) and Greene (2000, chapter 19) for instance. Let Y be the binary variable that describes switching behavior. $Y = 1$ indicates switching and $Y = 0$ no switching. Taking his search choice as given, a consumer switches suppliers if the expected gains exceed the switching costs, according to (1). The probability of that happening is

$$\begin{aligned}\Pr(Y = 1 : j) &= \Pr\left(\gamma^j > \omega\right) = P\left(g^j + \varepsilon_\gamma^j > \mathbf{x}'\boldsymbol{\beta}_\omega + \varepsilon_\omega\right) \\ &= P\left(\varepsilon^j < g^j - \mathbf{x}'\boldsymbol{\beta}_\omega\right),\end{aligned}$$

where $\varepsilon^j = \varepsilon_\omega - \varepsilon_\gamma^j$. If we assume that ε^j has the normal distribution with zero mean and variance σ_j^2 we have the probit model,

$$\Pr(Y = 1 : j) = \Phi\left(\beta_g g^j - \mathbf{x}'\boldsymbol{\beta}_\omega\right), \tag{3}$$

where $\Phi(\cdot)$ is the cumulative standard normal distribution function. The purpose and interpretation of the added parameter β_g is explained below. Assuming independence between individual observations we can specify the likelihood function as

$$L = \prod_{i=1}^{n} \left[\Phi\left(\beta_g g_i^j - \mathbf{x}_i'\boldsymbol{\beta}_\omega\right)\right]^{y_i} \left[1 - \Phi\left(\beta_g g_i^j - \mathbf{x}_i'\boldsymbol{\beta}_\omega\right)\right]^{1-y_i}, \tag{4}$$

where subscripts i indicate individual observations from a sample of n. The likelihood function (in logarithms) is then maximized using Newton's method as programmed in the Limdep econometrics package.

The results are shown in table 4. The first two columns show the parameter estimates and the corresponding marginal effects when the whole sample is used for estimation. In that case the expected gain is calculated based on observed search behavior. The third and fourth columns show estimates for the subset of consumers that actually conducted active search. The last two columns show the results for passive consumers or non-searchers. The marginal effects, in the even numbered columns are calculated using partial derivatives of the choice probability with respect to the exogenous variable in question and the sample mean, which is not exact in the case of dummy variables. Still, according to Greene (2000, page 878) the approximation is often surprisingly accurate.

Table 4: Estimates from the binary probit model for switching, conditional on search

Variable	Full sample		Active search		Passive search only	
	Est.	*M.E.*	*Est.*	*M.E.*	*Est.*	*M.E.*
g^j	0.554$^{3)}$	0.086$^{3)}$	0.401	0.118$^{2)}$	0.079	0.007
	(0.145)	(0.023)	(0.197)	(0.058)	(0.271)	(0.026)
Constant	-2.394$^{3)}$	-0.370$^{3)}$	-2.248$^{3)}$	-0.661$^{3)}$	-1.910$^{3)}$	-0.180$^{3)}$
	(0.313)	(0.045)	(0.617)	(0.165)	(0.412)	(0.040)
MALE	-0.070	-0.011	-0.457$^{2)}$	-0.135$^{2)}$	0.078	0.007
	(0.129)	(0.020)	(0.227)	(0.066)	(0.174)	(0.016)
AGE1	-0.049	-0.008	-0.227	-0.067	0.183	0.017
	(0.181)	(0.028)	(0.310)	(0.091)	(0.244)	(0.023)
AGE2	-0.111	-0.017	-0.097	-0.029	-0.113	-0.011
	(0.198)	(0.031)	(0.328)	(0.096)	(0.276)	(0.026)
INC1	0.486$^{2)}$	0.075$^{2)}$	0.497	0.146	0.367	0.035
	(0.175)	(0.026)	(0.324)	(0.094)	(0.231)	(0.021)
INC2	0.747$^{3)}$	0.115$^{3)}$	0.700$^{2)}$	0.206$^{2)}$	0.821$^{3)}$	0.077$^{3)}$
	(0.187)	(0.028)	(0.339)	(0.098)	(0.247)	(0.022)
INTNET	-0.005	-0.001	0.093	0.027	-0.255	-0.024
	(0.148)	(0.023)	(0.274)	(0.081)	(0.196)	(0.018)
ADPAP	-0.047	-0.007	0.249	0.073	-0.271	-0.026
	(0.146)	(0.023)	(0.274)	(0.080)	(0.188)	(0.018)
ADTV	-0.128	-0.020	0.053	0.016	-0.245	-0.023
	(0.131)	(0.020)	(0.232)	(0.068)	(0.172)	(0.016)
ADDIR	0.492$^{2)}$	0.076$^{2)}$	0.696	0.205$^{1)}$	0.391	0.037
	(0.215)	(0.032)	(0.431)	(0.124)	(0.272)	(0.025)
ARTIC	-0.033	-0.005	0.228	0.067	-0.156	-0.015
	(0.145)	(0.022)	(0.275)	(0.081)	(0.188)	(0.018)
OINFO	0.105	0.016	-0.237	-0.070	0.259	0.024
	(0.172)	(0.027)	(0.287)	(0.084)	(0.226)	(0.021)
N. Obs	856		201		655	
P(switch)	0.105		0.249		0.061	
LRI	0.090		0.098		0.091	

1) Significantly different from zero at 10 percent significance level

2) Significantly different from zero at 5 percent significance level

3) Significantly different from zero at 1 percent significance level

As could be expected, the first line confirms that the probability of switching is positively affected by the expected gains variable. Interestingly, the effect is not significant for passive consumers. Interpretation of the parameter estimates is postponed until section 8. Only a few other independent variables are significant in predicting the probability of switching. Income and the event of receiving direct mail advertisement are consistently significant factors, while gender is only a significant variable in the sub-sample of active searchers. Higher income increases the probability of switching, especially among active searchers, which can be interpreted as a negative effect of income on switching cost. Direct mail advertisements also have a positive effect on switching, again primarily within the sub-sample of active searchers.

An appropriate test for the effects of age and income is to test that the linear restrictions of both age variables are equal to zero, on the one hand, and both income variables, on the other. The results confirm that age is far from being a significant determinant in switching costs while income is very significant. We can not rule out the possibility that the strong income effect is not primarily related to the switching cost, as it may correlate with electricity expenditure and thereby with expected gain from switching. Additional variation in gains might be picked up by the income variable. When the probit model is re-estimated dropping the income variables, the estimated gain parameters are not significantly affected, which suggests that the problem is at least not serious. Giulietti, Price & Waterson (2001) also find income to affect the probability of switching suppliers in the UK gas market in a positive way. It should be noted, however, that their study involved a more extensive set of explanatory variables.

The significant and negative constant term is consistent with the switching costs story. When viewed in relation to other parameter estimates it seems as if variability in the measurable switching cost, or the deterministic part observable by the researcher, is small. That does not imply that consumer preferences are fairly homogenous but that it is difficult to predict the switching costs of consumers based on their observable characteristics (with the noteworthy exception of income groups). There can still be a large variation in switching costs between consumers which can not be attributed to observed variables.

The parameter of the expected gain g^j has a special interpretation. It was restricted to unity in the theoretical model, while it was added in the probit model as a scaling parameter so that the standard normal distribution could be applied.

Using this scale parameter we can now calculate the standard deviation of the error terms ε^j as $\widehat{\sigma}^j = \frac{1}{\beta_g^j}$, for $j = a$ and p, where β_g^j is the parameter corresponding to g^j in the sub-sample choosing alternative j,

$$\widehat{\sigma}^a = \frac{1}{\beta_g^a} = \frac{1}{0.401} = 2.494, \tag{5}$$

$$\widehat{\sigma}^p = \frac{1}{\beta_g^p} = \frac{1}{0.079} = 12.658, \tag{6}$$

in thousands of SEK. This is consistent with our previously stated hypothesis that the variance of the expected gain is larger for passive searchers than active searchers. This result is, however, not conclusive. The error terms ε^j stand for the stochastic part of the net benefit of switching, including the unexplained switching costs. Hence, we can not rule out that it is switching costs that are affected by search, rather than the expected benefits of switching. The difference between (5) and (6) is also not significant.

For testing purposes a full sample version of the model was estimated where the sub-sample models are nested, so that parameter estimates are identical to those in the last four columns of Table 4. The Wald test statistic for the restriction $\beta_g^a - \beta_g^p = 0$ is .96, so the hypothesis that these two parameters are equal cannot be rejected at any reasonable level of significance. Because the way the model is specified this is not a valid test of the hypothesis that search increases the expected gain from switching. We, however, find support for that hypothesis when estimating a model for expected gains in section 4. A Wald test for the invariance of the switching cost function between sub-samples, i.e., of all other parameters being equal in both sub-samples, has the statistic 18.59, and is compared with Chi-squared distribution with 12 degrees of freedom. The hypothesis of invariance is not rejected at 5% significance (but is narrowly rejected at 10%).

Based on these test results we assume in the following that predicted switching costs, as well as the standard deviations of the net benefit of switching, are independent of search. The common standard deviation of the net benefit of switching, based on the full sample regression model, is

$$\widehat{\sigma} = \frac{1}{0.554} = 1.805 \tag{7}$$

Table 5: Descriptive statistics of the predicted annual gain and switching cost, in Swedish kronur per year

Variable	*Mean*	*Std.Dev.*	*Minimum*	*Maximum*	*Cases*
g^a	878.1	468.0	-20.9	2,292.4	878
g^p	775.8	306.9	-11.4	1,567.7	878
w	3,309.3	667.3	2,032.2	5,036.0	867

and the expected deterministic part of the switching cost function is

$$w_i = -\widehat{\sigma}\mathbf{x}'\boldsymbol{\beta}_\omega,$$

based on the full sample. The expected gain is assumed to depend on search. Descriptive statistics of w are compared with the conditional expected gain from switching in Table 5. The high level of predicted switching costs may seem rather striking compared with the expected gains. After all it implies that practically no switches are predicted. This can be seen clearly in figure 2 where the estimated distributions of the deterministic part of the expected gain and switching costs are shown. This does not mean, however, that some switching is not to be expected, since the standard deviation of the stochastic part of the net gain is quite large and switching occurs with positive probability. It only means that it difficult to predict that a particular consumer will switch. Almost all consumers, irrespective of their characteristics, are more likely to stay with their incumbent supplier than to switch. Only in a realization where a consumer has a very low switching cost and very high expected gains, can we predict a particular switch. This does not mean, however, that we can expect only very few switches to occur. What is missing in figure 2 is the large standard deviation of the stochastic part of the net gain from switching (the difference between the gain and the switching costs).

In section 8 we'll discuss the effects of changes in switching costs on the probability of switching and its implications for public policy. The next step, however, is to consider the decision whether to become an active consumer or stay passive.

7 Search choice

So far we have seen that switching behavior depends to a large extent on previous search. The switching ratio is, for instance, four times higher for active consumers

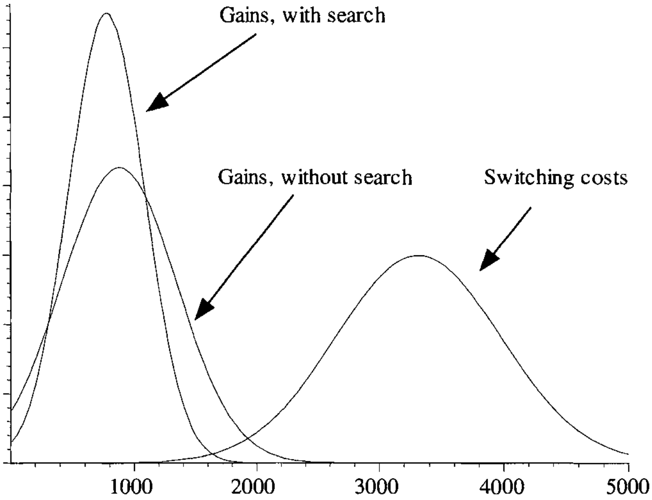

Figure 2: Probability density functions for predicted gains from switching and switching costs

than passive ones. Now we will take a close look at the choice whether to search actively for information about service alternatives or not, as well as the associated benefits and costs of searching. The decision to search actively for information can be considered as a separate choice problem similar to the one analyzed in the previous section where consumers compared expected gains from searching to the search costs. A decision rule analogous to (1) is to search actively if

$$b - \eta > 0, \tag{8}$$

where b is the perceived benefit of active search and η is the search cost. Both variables are household specific.

Creating a measure for the perceived benefit of search is complicated by the fact that it has to be derived from perceived net gains from switching suppliers - with or without active search. Even though active searching can not affect the true potential gain from switching, the perceived benefit can be affected by searching. Searching increases the number of alternative suppliers a particular consumer can choose, and hence raises the value of switching to the best alternative supplier. We have already found support for the hypothesis that the perceived gain of switching increases with active information. Search can also provide the consumer with better knowledge about the market and the likely effects of switching, so that the uncertainty about the net benefit of switching is reduced. Alas, we could only find suggestive evidence for this prediction, that standard deviation of the gains decreases with active information.

If we believe that consumers have rational expectations of the gains from switching, with and without active search, we can form a prediction of the perceived gains from search. Then $b^a = g^a - w$ and $b^p = g^p - w$ are unbiased estimates of the ex ante expected gain from switching conditional on search. The superscripts a and p refer to active and passive search respectively. The standard deviation of the net gain from switching was also estimated in the previous section. Since the difference between the standard deviation with and without active search is not significant we will use the full sample estimate calculated in (7). This implies that consumers expect the expected net benefit of switching to improve with search while not expecting any change in the accuracy of the prediction. After all, what we are focusing on here is the ex ante standard deviation of the perceived gains from switching. Even if we believe that consumers may improve their perceived gains from switching by performing an active search, it is far from obvious that consumers should realize that themselves, ex ante.

Let us further assume that the gains from switching are normally distributed, so that we have fully specified distributions of gains from switching. In the case of active searchers the p.d.f. is f^a with mean $b^a - w$ and f^p with mean $b^p - w$ in the case of passive consumers. These means are household specific, but the standard deviation is $\widehat{\sigma} = 1,805$ for all households, independent of search, as in (7). Only if the net benefit of switching turns out to be positive will search pay off. If the expected gains are negative, no search or switch is desired and no loss of utility occurs. As a result, the ex ante conditional expected gains of switching are

$$b^i = E\left[\max\left(g^i - w + \varepsilon, 0\right)\right] = \int_0^\infty x f^i(x)\, dx$$

for $i = a$ and p and $\varepsilon \sim N(0, \widehat{\sigma}_\varepsilon)$, where f^a is a normal p.d.f. with mean $g^a - w$ and standard deviation $\widehat{\sigma}_\varepsilon$. The consumer could, however, also benefit from switching

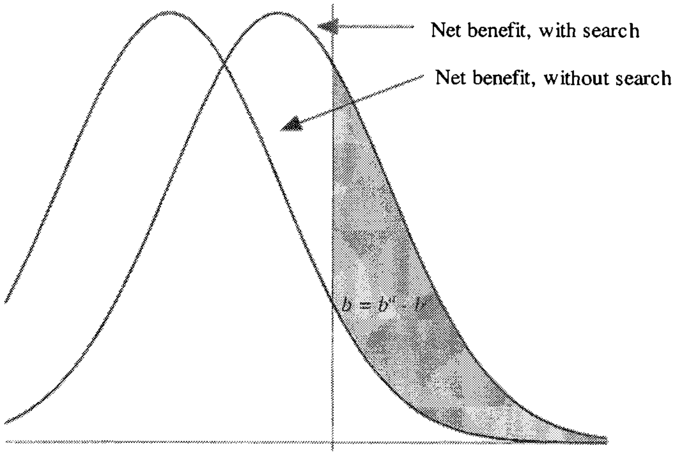

Figure 3: Expected benefit of search

suppliers even if he does not search actively. The expected benefit of search is then

$$b = b^a - b^p. \tag{9}$$

As illustrated in Figure 3, search shifts the distribution of gains from switching to the right, thereby increasing the expected realized gains by the amount represented by the grey area.

While we can calculate b for every individual we have to estimate the search cost, η. As before we have no obvious criterion for choosing variables in the estimation of η, but all the exogenous variables listed in Table 3 can play a role. Let Z be a dummy variable, taking the value 1 if a search takes place and 0 otherwise. The parameters of the probit model

$$\Pr(Z=1) = \Phi\left(\beta_b b - \mathbf{x}'_{\omega_\eta} \boldsymbol{\beta}_\eta\right),$$

are then estimated using maximum likelihood, as before. The results are reported in Table 6.

Consistent with the model, the single most important factor affecting the choice to search actively, is the expected benefit of search. Interpretation of the parameter estimates and the marginal effect is postponed until the next section. A few other

Table 6: Estimates from the binary probit model for active search

Variable	*Estimates*	*Marginal E.*
b	3.452[3)]	1.014[3)]
	(0.894)	(0.264)
Constant	-1.640[3)]	-0.482[3)]
	(0.217)	(0.060)
MALE	0.250[2)]	0.073[2)]
	(0.102)	(0.030)
AGE1	-0.234	-0.069
	(0.144)	(0.042)
AGE2	-0.200	-0.059
	(0.152)	(0.045)
INC1	0.210[1)]	0.062[1)]
	(0.124)	(0.036)
INC2	0.189	0.056
	(0.143)	(0.042)
INTNET	0.361[3)]	0.106[3)]
	(0.119)	(0.035)
ADPAP	0.155	0.046
	(0.118)	(0.035)
ADTV	0.042	0.012
	(0.107)	(0.031)
ADDIR	0.135	0.040
	(0.138)	(0.040)
ARTIC	0.231[2)]	0.068[2)]
	(0.116)	(0.034)
OINFO	0.323[2)]	0.095[2)]
	(0.136)	(0.040)
N. Obs	867	
P(search)	0.23	
LRI	0.072	

[1)] Significantly different from zero at 10 percent s.l.
[2)] Significantly different from zero at 5 percent s.l.
[3)] Significantly different from zero at 1 percent s.l.

variables, associated with search costs, are significant determinants for an active search to take place. The gender of the respondent is relevant; males are more likely to search actively or have lower search costs on average than women. If there is a general tendency for men to be active searchers to a greater extend than women, contrary to what Moshkin and Shachar (2000) presume, or simply that electricity is a particularly "masculine" commodity is not clear. Three variables, representing different forms of passive information, turn out to be significant. Having read newspaper articles about the electricity market reform or having received information from "other sources", in most cases from colleagues or friends, are quite significant variables. The latter especially, with a marginal effect of nearly .1. Internet access seems to have the strongest impact though, with a parameter significantly different from 0 at the 1% level of significance and a marginal effect of roughly .1. In other words, the probability of an active search is on average 10 percentage points greater for households with internet connection. This is consistent with the author's own experience that the most accessible sources of information about electricity prices are found on the internet.[8] Advertising, either through newspapers, television or direct marketing, is not found to be significant. After all, the purpose of advertising is often to establish brand recognition rather than providing information about price or other service attributes. Hence, it is not surprising that the estimated effects of advertising are inconclusive.

Based on these results, passive information in general seems to support active searching for information. This is by no means trivial, as one can imagine "free" passive information being a substitute for "costly" active information. But the contrary seems more likely; that penetration of passive information induces active searching. This indication is especially true for types of passive information that are likely to become more prevalent in the near future; through access to the internet and the dissemination of information by word-of-mouth (as measured by the OINFO variable). The OINFO variable is particularly important in this respect because occurrences of this form of information transmission are relatively infrequent in the current sample, but likely to grow over time.

As in the case of switching costs, we can use the parameter estimates to calculate the predicted search costs for each respondent and compare with the estimated one year gain from active search. The key descriptive statistics are listed in table 7

[8] Examples are http://www.sparapengar.se, http://www.kundkraft.se, and most recently http://www.konsumentverket.se.

Table 7: Descriptive statistics of the estimated benefit of search and searching cost, in swedish kronur per year

Variable	*Mean*	*Std.Dev.*	*Minimum*	*Maximum*	*Cases*
b	20.1	51.7	-14.9	323.4	867
$\widehat{\eta}$	246.9	94.3	13.4	503.7	867

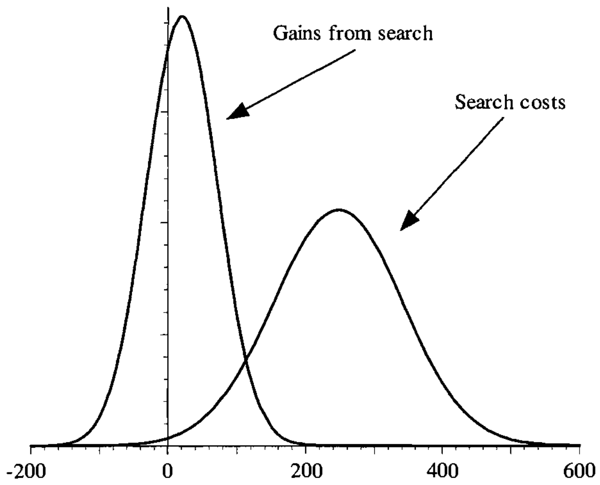

Figure 4: Probability density functions for predicted gains from search and search costs

As shown, even more clearly in figure 4, the central tendency of search costs is considerable above the central tendency of the gains from search. If we take into account that the standard deviation of the random part of the net benefit, more active searching will take place than suggested by the figure alone.[9]

8 Implications for policy

In the two previous sections we have been concerned with possible determinants of switching costs and search costs, as well as the assessment of the scale and distribution of these two costs, compared to the monetary gain from switching and

[9]The standard deviation of the random part is $\widehat{\sigma}_\varepsilon = \frac{1}{3.452} = 0.289$ in thousands of SEK.

searching respectively At this point we would like to put these results into context and to illustrate how important these costs are for policy.

It is worth repeating that the share of consumers switching from the incumbent to competitors is not the best measure of market performance in itself. What is important is how the persistence translates into market power, and how that market power is used or abused. That goes beyond the scope of this study but is considered in some detail in chapter 2. That study illustrates that market equilibria can be fragile with respect to the distribution of search and switching costs. We can still say something about the effects of small changes in these costs, in the spirit of comparative statics, assuming the prices are held fixed.

Most suggested policy measures intended to boost competition can be classified in two broad categories. Those that supposedly affect switching costs and those meant to affect search costs. An example in the former category is shopping credits awarded when switching.[10] Public provision of price information is an example of the latter. All such measures bear costs and in order to compare their relative efficiency, the costs of implementing a specific policy have to be compared with the efficacy of the respective actions. This is difficult to do, mainly because the two costs discussed in this paper are essentially linked. Consider, for example, a consumer who neither performed active search nor switched suppliers. That does not mean that he necessarily has high search costs. His search cost might be small, while his cost of switching is large. Such a consumer might prefer not to search, because his expected gain from searching is small, as he expects his switching cost to outweigh the benefit of switching with a large probability.

The marginal effects reported in tables 4 and 6 illustrate the implied effects of changes in search and switching costs on choice probabilities. Since utility is linear in expected benefits and costs of switching, the marginal effect parameter in the first row of table 4 represents the effect of a SEK 1000 decrease in switching costs on the average probability of a switch taking place. For the full sample the marginal effect is .086. For the subsample of active consumers the marginal effect is .118 and for the subsample of consumers not searching actively it is .007. In other words, if switching cost decreases by SEK 1000, the probability that the average actively searching consumer switches increases by .12 percentage points. The effect on passive searchers is negligible and not significantly different from zero. A corresponding

[10]Since shopping credits are usually financed by a general energy levy, they also have the effect of increasing the default prices relative to entrants prices, though only temporarily.

marginal effect of a SEK 1000 decrease in search cost has the impact of increasing the probability of active search by 101.4 percentage points. A decrease of this scale is not feasible, as the average search cost is estimated to be just below SEK 250. The marginal effects are linear extrapolations based on the derivative of the respective probability function with respect to each cost variable. Considering large changes like this can be misleading.

Alternatively we can consider the effect of a percentage change in each cost on the switching and search probabilities. In that case the probability of switching increases by .39 percentage points in the case of active searchers, and .02 percentage points in the case of passive searchers, when switching costs decrease by one percent across the board. Similarly when searching costs decrease by one percentage the probability of active search increases by .25 percentage points. We can also calculate the change in choice probabilities by reestimating a restricted model and calculate the choice probabilities for the base case and a new counterfactual case where the search or switching costs are reduced. The average of the change in the choice probability is almost the same as when the marginal effects parameters were used. Due to the nonlinearity of the probit model the effects are however very different for each consumer depending on his initial probability of switching.

It is more difficult to assess what effect a decrease in search costs would have on switching without knowledge about the correlation between search and switching costs. These results suggest, however, that active search is more or less a prerequisite if policy measures designed to reduce switching costs are to have a widespread effect. Hence, it makes little sense to discriminate between policy measures targeted at search or switching costs independently. The two are interdependent.

The above analysis only provides a snapshot of a dynamic process. One point, made earlier, is that some important determinants of search costs are likely to change in the near future. One was the spread of the internet and the other was the element of personal contacts. The first can be considered more or less an exogenous phenomenon, but the second is truly endogenous. As more people switch suppliers, the knowledge of the benefits of switching is likely to spread with increasing speed for some time. It is therefore interesting to hypothesize about what is likely to happen in the future as passive information spreads. A simple counterfactual case is when everyone has received all types of passive information. Using the previously estimated parameter estimates we can calculate the effect this has on the search costs and the choice probabilities. The average search cost is SEK 84.9, compared with 246.9 in the benchmark case. This drastic reduction in search costs, through dissemination of passive information, translates into an increase in the probability of active search by 18.04 percent points on average. The expected share of active searchers is then 41 percent compared with 23 percent in the actual data. Without any other change in search or switching costs, this would then translate into an increase in the switching ratio from 10 percent to 14 percent.

9 Conclusion

Taking a simple discrete choice model and observed behavior in the retail electricity market in Sweden we have estimated, a) the expected gains from switching suppliers conditional on prior information, b) the expected gain from being an active consumer, c) the expected cost of switching suppliers, and d) the expected cost of searching actively for information. Within this framework the observed persistence to switch suppliers is primarily attributed to switching costs. The average expected switching costs are approximately 10 times the expected gain from switching. The estimate of average expected search costs is much lower but still much larger than the expected gain from searching.

Search costs play an important role nevertheless, since passive consumers are not likely to respond to changes in switching costs on average. In particular, we find that the marginal effect of changes in switching costs on the probability of switching suppliers is very low and not significantly different from zero in the case of passive consumers. Active consumers on the other hand are likely to respond to changes in switching costs quite significantly. As an example, we can expect that a decrease in switching costs by a third of the average level would induce twice as many active consumers to switch suppliers while increased switching among passive consumers is likely to be negligible.

When considering the choice of searching for relevant information in more detail, we come across a second complementarity. Namely, that the penetration of various types of passive information seems to encourage, rather than discourage active search for information. This result is by no means trivial as it is easy to argue the opposite result on the basis of decreasing returns to search.

Without a measure of the cost of reducing these costs, we can hardly compare the costs at par and determine which is a more suitable target for policy measures.

Both matter, and each is dependent on the other. A reduction in search costs, by itself, will only have a marginal effect on consumer switching, while a reduction in switching costs is likely to affect only active consumers.

The gains from switching suppliers, and the derived gains from search, stem from the considerable price dispersion in the market. If search and switching costs change, the prices are likely to change as well. A full analysis requires a model of competition between suppliers of electricity when consumers both face search and switching costs. This is the subject of the following chapter.

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Chapter 2

Price Duopoly in a Default Service Market with Search and Switching Costs

Price Duopoly in a Default Service Market with Search and Switching Costs*

Jon Thor Sturluson

Abstract

This paper develops a simple model of a asymmetric price duopoly, where one firm is an incumbent with an established relationship to all consumers, while the other firm is a new entrant in the market. Consumers have different consumption levels and can face a switching cost or a search cost. Retail electricity markets are the prime example. Given conditions on the distribution of these costs, an asymmetric equilibrium in prices exists. In equilibrium, the rate of switching can be a bad measure of market performance. A decrease in switching costs affects prices for the benefit of all consumers and not only those who choose to switch. A decrease in search costs is likely to be primarily in the interest of those consumers that do not wish to search. This suggests that consumers may be facing a free-rider problem, discouraging search as well as switching.

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1 Introduction

The issue of competition in electricity markets, or rather the possible lack of competition, has received considerable attention since the early 1990s, when England/Wales and Norway pioneered in deregulating their electricity supply industries. Important early contributions to an expanding literature were made by Green and Newbery (1992) and von der Fehr and Harbord (1993). Even though these two studies used quite different modelling frameworks, their main conclusions were similar: that policymakers should be concerned with market power in wholesale markets for electricity, given the concentrated market structure in England and Wales. This view is generally supported by empirical studies (see for instance Wolfram, 1999). Market power need not be a serious problem, however, in markets with relatively low concentration, except in peek demand hours when transmission constraints are binding (Johnsen, Verma and Wolfram, 1999).

In terms of explicit theoretical models, less attention has been paid to market power issues on the retailing side of electricity markets. Not surprising perhaps, as deregulation of retail markets has lagged behind the transformation of wholesale markets. Noteworthy exceptions are Green and McDaniel (1998) and Green (2000), who models retail competition between an incumbent and several entrants. Initially, all consumers have an established relationship with the incumbent and incur a switching cost when buying from one of the entrants, who offer horizontally differentiated service alternatives. The switching cost translates into market power for the incumbent to enjoy, who charges prices well above its costs. Hence, the question is raised whether we may be better off with regulated retail markets, at least for households. Joskow (2000) suggests that electricity retail competition could be skipped altogether - that consumer may be better off if charged a regulated markup (e.g., to cover distribution and billing costs) on top of the wholesale price. This opinion is not shared by all and has for instance been criticized by Littlechild (2002), who beliefs that retail competition will play an important and valuable role in the electricity sector; both as an information transmission mechanism and a source of value-added services.

Several recent empirical studies have emphasized search costs, as well as switching costs, as the cause of consumer persistence in different product markets. See for instance Schlesinger and der Schulenburg (1999), Moshkin and Shachar (2000) and Giulietti et al. (2001). In the preceding chapter, we found evidence from the

Swedish electricity market, that both search costs and switching costs are important determinants of consumer behavior and that the distribution of these costs may matter. Still, as in all related papers, prices were treated as exogenously determined and independent of the distribution of the search and switching costs.

The purpose of this paper is to endogenize pricing decisions in an imperfectly competitive environment of this kind. Two firms, an incumbent and an entrant, compete by setting prices simultaneously. Consumers can either face switching costs or search costs (or neither), which creates downwards sloping derived demand functions even though demand is assumed to be inelastic on the aggregate. The firms are not on level footing, as the incumbent is the default service provider. All consumers have an initial relationship with the incumbent and continue to subscribe to his services unless they make an active decision to change suppliers, in which case they may incur switching costs. Furthermore, some consumers are only informed about the incumbents price while they incur a search cost if they choose to learn the rivals price as well. A large amount of theoretical models involving search costs[1] or switching costs[2] can be found in the literature. But the interplay of the two has not been studied before in the way done here.

The paper proceeds as follows. Some preliminaries, primarily the demand side of the market, are introduced in the next section. In section 3 we start off with the special case when consumers either face switching costs or can be classified as shoppers (always choose the firm offering the lower price). A particularly interestingly observation made, is that market shares turn out to be independent of the magnitude of the switching cost in equilibrium. Section 4 involves the opposite extreme case, when consumers only face search costs. It turns out that no equilibrium in prices exists, in pure or mixed strategies. Section 5 presents the combined model when both types of consumers coexist. Equilibrium in prices is developed and comparative statics explored. Section 6 concludes.

[1]See for instance Stigler (1961), Diamond (1971), Reinganum (1979), Stiglitz (1987) and Stahl (1989)

[2]See for instance Weizsäcker (1984), Klemperer (1987*a*, 1987*b*, 1995) and Farrell & Shapiro (1988).

2 Some preliminaries

We start by describing some basic elements of the model. Even though the model is meant to represent important characteristics of electricity retailing and similar markets, it is far from being a complete characterization of all important aspects of such real-world markets. Important omissions and interesting extensions, e.g., more than two firms and multiple periods, are discussed in the conclusions below.

Two firms sell a homogenous good in a geographically isolated market. Firm 1 is an the default service provider as well as an incumbent, with an established relationship with all consumers. Firm 2 is new to the market - an entrant. Picture, for instance, a single electricity distribution network area as the relevant market, where the established utility is the default service provider - provides all inactive consumers with electricity. For simplicity, costs are normalized to zero.

The market interaction is modelled as a three-stage game:

Stage 1 Both firms choose a price, $p_i \in \mathbb{R}_+$ for $i \in \{1, 2\}$, simultaneously.

Stage 2 Having observed p_1 consumers with positive search cost choose to search or not. Consumers with zero search cost observe both prices automatically.

Stage 3 Consumers choose between firm 1 and 2.

We start by defining consumers' preferences and optimal choices in the remainder of this section, and then turn to firms' behavior in the following section. Let there be a continuum of consumers with individual demand levels in the interval $[1, \infty)$. Demand is price inelastic, up to a reservation price r when it becomes zero, and varies over the population according to a distribution function $F(q)$. It is particularly convenient to use the distribution function $F(q) = 1 - \frac{1}{q^2}$ for $q \in [1, \infty)$ and $f(q) = 0$ for $q < 1$. The convenience lies in the fact that market shares turn out to be linear in prices and uninteresting corner solutions are avoided.

Consumers are furthermore, divided into three groups named A, B and C. In group A, preference over suppliers is represented by the utility function

$$u_A(i) = r - p_i q, \tag{1}$$

where $i \in \{1, 2\}$ indicates the respective firm. The reservation price, r, is assumed to be large so that the market is always covered. This implies that, given p_1 and p_2,

Table 1: Taxonomy of consumers and their preferences

Group label	*Description*	Will search if	*Will switch if*
A	Neither switching nor search cost	–	$p_2 < p_1$
B	Switching cost only	–	$p_2 + \frac{\omega}{q} < p_1$
C	Search cost only	$p_e + \frac{\eta}{q} < p_1$	$p_2 < p_1$

a consumer of type A prefers to switch to firm 2, if and only if, $u_A(2) > u_A(1) \iff p_2 < p_1$. In other words, these "shoppers" are only concerned with the relative price and have no disutility from searching or switching. Consumers of type B incur a switching cost ω if they switch to firm 2, so their utility is

$$u_B(i) = r - p_i q - \omega \times I_\omega, \tag{2}$$

where I_ω is an index function taking the value 1 when $i = 2$ and 0 otherwise. Consumers of type B prefer to switch from firm 1 to 2 if and only if $u_B(2) > u_B(1) \iff p_2 + \frac{\omega}{q} < p_1$.

While consumers in groups A and B observe p_1 and p_2 before choosing a supplier, C consumer only observe the incumbent's price p_1 to start with. Only if they perform search at the cost η, is p_2 revealed to them and they can choose whether to switch suppliers or not. We let p_e denote (C) consumers' degenerate prior belief about p_2 where applicable.[3] With some abuse of notation, the ex ante expected utility when purchasing from firm 2 is

$$u_C(e) = r - p_e q - \eta$$

compared with the certain $u_C(1) = u_A(1)$. For these consumers, the decision problem has two stages. Consumers C first choose to search if and only if $u_C(e) > u_C(1) \iff p_e + \frac{\eta}{q} < p_1$. Thus, p_e is a trigger price with respect to p_1. Search reveals p_2, and the second stage decision problem, for those who choose to search, is identical to A's problem: switch suppliers if $u_C(2) > u_C(1) \iff p_2 < p_1$. The decision rules derived from the described utility functions are summarized in table 1.

If all consumers belonged to group A, then neither search- nor switching costs would play a role. The unique Nash equilibrium would be for the incumbent to apply marginal cost pricing, $p_1 = 0$. By assumption, consumers stay with the incumbent if they are indifferent between suppliers, so the incumbent would maintain

[3]In some cases the belief is nondegenerate and is represented by the distribution function F_e.

its monopoly, $s_1 = 1$ while any $p_2 \in \mathbb{R}_+$ together with $p_1 = 0$ would be be a Nash equilibrium.

In the following we will always assume that there is a positive mass in group A, or in other words, that at least some consumers always buy at the lowest price. We will then consider different cases when consumers of types B and C are also about.

3 Switching cost

The simplest case considered here is when consumers only face a switching cost or no lock-in cost at all.[4] That is, when the mass of consumers in group C is zero and the mass in groups A and B is strictly postitive (i.e., α_A and $\alpha_B > 0$ and $\alpha_A + \alpha_B = 1$).

For a given strategy profile $p = (p_1, p_2)$ consumers in group A will choose to purchase from 1, if and only if, $p_1 \leq p_2$. Consumers in group B will choose firm 1 if the cost of its service is no greater than firm 2's in addition to the switching cost, or if

$$p_1 q \leq p_2 q + \omega. \tag{3}$$

Since q is continuous and has positive mass for all $q \geq 1$ we know that, if $p_1 > p_2$, there exists a strictly positive consumption level $q^* = \frac{\omega}{p_1 - p_2}$ associated with a particular consumer who is indifferent between choosing firm 1 and firm 2. The inequality (3) is only true for consumers with $q \leq q^*$. The firms' derived share in the demand from B consumers is

$$s_1^B = \int_1^{q^*} qf(q)\,dq = 1 - \frac{p_1 - p_2}{\omega} = \frac{\omega - p_1 + p_2}{\omega} \text{ and} \tag{4}$$

$$s_2^B = \int_{q^*}^{\infty} qf(q)\,dq = \frac{p_1 - p_2}{\omega}. \tag{5}$$

Aggregate profits are then

$$\pi_1(p_1, p_2) = p_1 \times \begin{cases} \alpha_B \frac{\omega - p_1 + p_2}{\omega} & \text{if } p_1 > p_2 \\ p_1 & \text{if } p_1 \leq p_2 \end{cases} \text{ and} \tag{6}$$

$$\pi_2(p_1, p_2) = p_2 \times \begin{cases} \left(\alpha_A + \alpha_B \frac{p_1 - p_2}{\omega}\right) & \text{if } p_1 > p_2 \\ 0 & \text{if } p_1 \leq p_2 \end{cases}. \tag{7}$$

where the upper lines of (6) and (7) apply when both firms have positive market

[4]The term lock-in costs is used as a collective term for search and switching costs.

shares. The lower line refers to the case when firm 1 undercuts firm 2. For a sufficiently few consumers with zero switching cost, i.e., for a sufficiently low α_A, there exists a unique pure strategy Nash equilibrium in prices.

Proposition 1 *When consumers either face no search or switching costs (group A) or only switching cost (group B) and the share of consumers in group A, α_A, is less than $\frac{7-3\sqrt{5}}{2} \approx 0.15$,*

$$\begin{aligned} p_1^* &= \frac{1}{3}\frac{2-\alpha_A}{1-\alpha_A}\omega \text{ and} &(8)\\ p_2^* &= \frac{1}{3}\frac{1+\alpha_A}{1-\alpha_A}\omega, &(9)\end{aligned}$$

are unique pure strategy Nash equilibrium price strategies.

Proof. First observe that $p_1 = p_2 > 0$ cannot be an equilibrium. Firm 2 increases its payoff discontinuously by undercutting. $p_1 = 0$ is not an equilibrium either as firm 1 can increase its payoff by raising its price, irrespective of p_2. Neither can $p_2 > p_1$ be an equilibrium. Firm 1 would then prefer to only sligtly undercut p_2 in which case firm 2 could increase its payoff discontinuously by setting $p_2 < p_1$, as long as $p_1 > 0$.

All we are left with is the case when $p_1 > p_2$. Then the two firms' first order conditions are

$$\begin{aligned} (1-\alpha_A)\frac{\omega - 2p_1 + p_2}{\omega} &= 0 \text{ and} &(10)\\ \alpha_A + (1-\alpha_A)\frac{p_1 - 2p_2}{\omega} &= 0 &(11)\end{aligned}$$

where we use the fact that $\alpha_A + \alpha_B = 1$. The payoff functions are strictly concave in prices so the solution to (10) and (11) yields jointly maximizing profits. Solving (10) and (11) together yields (8) and (9) as equilibrium candidates. The profits associated with this strategy profile are respectively,

$$\begin{aligned} \pi_1^* &= \frac{1}{9}\frac{(2-\alpha_A)^2}{1-\alpha_A}\omega_h \text{ and}\\ \pi_2^* &= \frac{1}{9}\frac{(1+\alpha_A)^2}{1-\alpha_A}\omega_h,\end{aligned}$$

where the superscript $*$ indicates the candidate equilibrium.

If firm 2 were to deviate, it would never choose $p_2 \geq p_1$ as it would result in zero profits. But since p_2^* is the optimal strategy when $p_2 < p_1 = p_1^*$ no deviation is profitable. If firm 1 were to deviate, it could do no better than to set $p_1 = p_2 - \varepsilon$ and receive $\pi_1^d = \frac{1}{3}\frac{1+\alpha_A}{1-\alpha_A}\omega$. The sign of $\pi_1^d - \pi_1^*$ equals the sign of

$$\frac{1-\alpha}{\omega}\left(\pi_1^d - \pi_1^*\right) = \frac{1}{3}(1+\alpha_A) - \frac{1}{9}(2-\alpha_A)^2 = \frac{7}{9}\alpha_A - \frac{1}{9} - \frac{1}{9}\alpha_A^2$$

which is strictly positive for $\alpha_A \in \left[\frac{7-3\sqrt{5}}{2}, 1\right]$. For $\alpha \leq \frac{7-3\sqrt{5}}{2}$ the expression is non-positive, so that neither firm gains from deviating from (p_1^*, p_2^*) and so the profile is a Nash equilibrium. If, however $\alpha_A \in \left(\frac{7-3\sqrt{5}}{2}, 1\right]$ firm 1 prefers to deviate and undercut p_2. Above we showed that such a profile is never an equilibrium. ■

If the share of A consumers is too high, firm 1 prefers to undercut p_2^* slightly rather than choose p_1^*. The game does not, however, collapse to a Bertrand outcome as firms compete vigorously for the relatively large group of A consumers. A downward spiral in prices would ultimately make it profitable for firm 1 to increase its price to gain more from its captured customers in group B. That would trigger an increase in p_2 and another price cycle begins.

If, however, α_A is small enough an equilibrium in prices (p_1^*, p_2^*) exists, implying the market shares

$$s_1^* = (1-\alpha_A)\frac{1}{3}\frac{2-\alpha_A}{1-\alpha_A} \text{ and} \tag{12}$$

$$s_2^* = \alpha_A + (1-\alpha_A)\frac{1}{3}\frac{1-2\alpha_A}{1-\alpha_A}. \tag{13}$$

Prices and market shares are affected by two parameters: the share of shoppers α_A, and the level of the switching cost ω.

Corollary 1 *When consumers either face no search or switching costs (group A) or only switching cost (group B) and the share of consumers in group A, α_A, is less than $\frac{7-3\sqrt{5}}{2} \approx 0.15$, a small increase in the share of shoppers (α_A) leads to:*

1. *an increase both firms' prices.*

2. *a decrease in the incumbent's market share.*

Proof. The equilibrium prices (8) and (9) are established in proposition 1. The market shares follow straight from applying (8) and (9) to the market shares implicit in (6) and (7). The result is then found by taking partial derivatives, $\frac{\partial p_1^*}{\partial \alpha_A} = \frac{1}{3}\frac{\omega}{(1-\alpha_A)^2} > 0$, $\frac{\partial p_2^*}{\partial \alpha_A} = \frac{2}{3}\frac{\omega}{(1-\alpha_A)^2} > 0$, $\frac{\partial s_1^*}{\partial \alpha_A} = -\frac{1}{3} < 0$, $\frac{\partial s_1^*}{\partial \alpha_A} = -\frac{1}{3} < 0$ and $\frac{\partial s_2^*}{\partial \alpha_A} = \frac{1}{3} > 0$. ■

It may seem unintuitive that a relative increase in the number of shoppers leads to an increase in prices. The reader might expect more intense competition as the number of shoppers increases. But, since all shoppers are served by firm 2 the important effect of this change is that firm 1's derived demand function becomes less elastic (steeper), and thereby incites an increase in p_1. In equilibrium firm 2's price increases as well, since prices are strategic compliments, but not by as much as p_1 increases. As a result, firm 2's share in the market increases. The assumption that consumers' demand level q is independent of α_A is critical. If, for instance, only those consumers with the highest q would move from group B to A, there would be no effect on prices (as those consumers would switch to firm 2 and firm 1's payoff would be unaffected by a slight change in α_A).

Corollary 2 *When consumers either face no search or switching costs (group A) or only switching cost (group B) and the share of consumers in group A, α_A, is less than $\frac{7-3\sqrt{5}}{2} \approx 0.15$, a small decrease in the switching cost ω:*

1. *leads to a decrease in both firms' prices.*

2. *leaves market shares unchanged.*

Proof. The result is found by taking partial derivatives with respect to ω of the equilibrium prices established in proposition 1 and the accompanying market shares: $\frac{\partial p_1^*}{\partial \omega} = \frac{1}{3}\frac{2-\alpha_A}{1-\alpha_A} > 0$, $\frac{\partial p_2^*}{\partial \omega} = \frac{1}{3}\frac{1+\alpha_A}{1-\alpha_A} > 0$, $\frac{\partial s_1^*}{\partial \omega} = 0$ and $\frac{\partial s_2^*}{\partial \omega} = 0$. ■

A decrease in prices as a result of a decrease in switching cost should not come as a surprise. More interesting is that market shares are left unchanged. In other words, a decrease in switching costs does not affect the rate of switching from the incumbent to the entrant. This is particularly noteworthy, as the low share of household consumers that have switched suppliers for electricity, is often viewed by regulators as a major concern (see for instance Riksrevisionsverket, 2000, for the cases of electricity and telephone in Sweden). A reduced switching costs is still beneficial for consumers through lower prices, especially for those of firm 1.

4 Search cost

As a second step consider a different special case when the mass of consumers in groups B and D is zero. That is, when consumers have no switching cost while a large share of consumers, α_C, has a positive search cost η. The share of consumers that do not face a search cost is α_A where $\alpha_A + \alpha_C = 1$. Consumers with zero search cost face the same have a simple choice as before. Consumers with positive search cost do not observe firm 2's price automatically. They have to decide whether to search or not, having only observed firm 1's price.

A consumer with consumption level q can gain from search, if it turns out that $p_2 < p_1$. To begin with, assume that all consumers of type C (with positive search cost) have a common degenerate believe about firm 2's price, p_e, Their strategy can be expressed with a trigger price level t, to search if and only if firm 1's price exceeds the trigger level, i.e., when $p_1 > t$. Consumers then choose a trigger price that maximizes their expected utility. Since consumers have different consumption levels the trigger is a decreasing function of q:

$$t(q) = p_e + \frac{\eta}{q}. \tag{14}$$

The marginal consumer is the one who is indifferent between search and no search, and has a trigger level equal to p_1. Consumers with larger consumption levels will search, others will not. The share of C consumers that search is then

$$\frac{p_1 - p_e}{\eta},$$

analogous to (5). After performing a search, a consumer selects the firm that offers the lowest price.

Now, turn to the first stage where firms choose prices simultaneously. The payoff functions of firms 1 and 2 are:

$$\pi_1(p_1, p_2 : p_e) = p_1 \begin{cases} (1-\alpha_A)\frac{\eta - p_1 + p_e}{\eta} & \text{if } p_1 > p_2 \text{ and } p_e \\ (1-\alpha_A) & \text{if } p_1 > p_2 \text{ and } p_1 \le p_e \\ 1 & \text{if } p_1 \le p_2 \end{cases} \quad \text{and} \tag{15}$$

$$\pi_2(p_1, p_2 : p_e) = p_2 \begin{cases} \alpha_A + (1-\alpha_A)\frac{p_1 - p_e}{\eta} & \text{if } p_1 > p_2 \text{ and } p_e \\ \alpha_A & \text{if } p_1 > p_2 \text{ and } p_1 \le p_e \\ 0 & \text{if } p_1 \le p_2 \end{cases} . \tag{16}$$

The first lines of (15) and (16) describe the most important case, when firm 1 chooses a higher price while consumers anticipate firm 2 having a lower price. Then firm 2 supplies all A consumers and has the market share $\frac{p_1 - p_e}{\eta}$ among C consumers. The second lines give the payoffs when firm 1 has the higher price, but consumers falsely expect firm 2 to have the higher price. Then the market is split so that firm 2 gets the A consumers and firm 1 the C consumers. Finally, line three shows the situation if firm 1 underbids firm 2. Irrespective of beliefs, firm 1 would then grab the whole market.

Notice first, that for any p_e, π_2 is maximized when $p_2 = p_1 - \varepsilon$, where ε is an arbitrary small number. This is because p_e is not affected by p_2. Assume that consumers anticipate this and rationally expect $p_2 = p_1 - \varepsilon$, then firm 1 would benefit by undercutting slightly and grab the whole market. This is the key to the following result.

Proposition 2 *When consumers either face no search or switching costs (group A) or only search cost (group C) there exist no pure-strategy perfect Bayesian equilibrium (PBE).*

Proof. For any given belief, p_e, firm 2's pure strategy best response is to set $p_2 = p_1 - \varepsilon$. Bayesian updating on behalf of consumers therefore requires that $p_e = p_1 - \varepsilon$. Consequently, no consumers with positive search cost will ever search, as they expect the price difference to be virtually zero. This gives firm 1 the opportunity to undercut firm 2's price slightly and receive a discreet jump in profits. But firm 2 would also like to undercut this new price of firm 1. Hence a cycle of undercutting can go on forever, or until the price is sufficiently low so that firm 1 would earn more by setting prices equal to r and sell only to consumers with positive search cost. But firm 2's best response to that is to set $p_2 = r - \varepsilon$ and the downward spiral of prices starts over again. ■

The nonexistence of pure strategy equilibria is not an unexpected result and in fact a general result in search cost models with an atom of consumers with zero search costs (see for instance Reinganum, 1979). But a mixed-strategy equilibrium usually exists in such models. In our case, however, there is also a problem with finding an equilibrium in mixed strategies.

Proposition 3 *When consumers either face no search and switching costs (group A) or only search cost (group C) there exist no mixed-strategy perfect Bayesian equilibrium.*

Proof. A mixed-strategy perfect Bayesian equilibrium consists of probability distributions over a subset of the firm's feasible price's, F_1 and F_2 and a belief, also in the form of a probability distribution, F_e. Let $\left[p_i^\ell, p_i^u\right] \in [0, s]$ be the support of firm i's mixed strategy. We prove nonexistence in four steps.

1) The payoffs are as follows:

$$\pi_1 = p_1 \left[\begin{array}{c} (\beta + s(p_1 : f_e))(1 - F_2(p_1)) \\ +(1-\beta)(1 - s(p_1 : f_e)) \end{array} \right] \text{ and} \tag{17}$$

$$\pi_2 = p_2 \left[(\beta + s(p_1 : f_e))(1 - F_1(p_2)) \right] \tag{18}$$

where $s(p_1 : f_e) = \max \left[\frac{p_1 - \int_{p_2^e}^{p_1} x f_e(x) dx}{\eta}, 0 \right]$ is the aggregate demand of searchers, i.e., type C consumers who prefer to search, as a function of p_1 taking the belief of firm 2's strategy as given.

2) F_1 and F_2 are atomless in equilibrium. If either (or both) firm's strategy is a distribution with an atom, the other firm would be able to increase it's profits discontinuously by undercutting the atom-price level (Stahl 1989). It is straightforward that a belief F_e is not consistent unless it is also atomless.

3) The lower bound of the support of price distributions cannot be lower for firm 2 than for firm 1. Assume $p_2^\ell < p_1^\ell$. Then from (18) it is clear that whenever $p_2 < p_1$, firm 2 prefers to increase p_2, since $F_1(x) = 0$ for $x \leq p_1^\ell$. Any $p_2 < p_1^\ell$ is strictly dominated by $p_2 = p_1^\ell$. With an atomless distribution (1) the probability of $p_1 = p_1^\ell$ is zero and hence $p_2 = p_1^\ell$ is preferred to $p_1^\ell - \varepsilon$ for any $\varepsilon > 0$.

4)$p_1^\ell < p_2^\ell$ can't either be true in equilibrium, as any $p_1 = p_2^\ell - \varepsilon$ for any $\varepsilon > 0$ is strictly dominated. Given a consistent belief $f_e = f_2$, we have $s(p_1 : f_2) = 0$ and $F_2(p_1) = 0$. Then, according to (17) the payoff is strictly increasing in p_1. ∎

The reason for this dismal result is that firm 2 has under no circumstances any locked-in consumers. A slightly different model with more symmetric firms would resolve the problem. We can also show that with discrete strategy space we can find an equilibrium in mixed strategies. What is more interesting though, for our purposes, is to explore if the existence problem can be solved by simply allowing for a positive mass of B consumers as well as C consumers.

5 Switching and search costs

A more realistic setting is when locked-in consumers face either search or switching costs. That is, when all three groups A, B and C have a strictly positive mass. In a similar fashion as in section 3 we first present a pure strategy equilibrium and the conditions under which it exists and then turn to some interesting comparative statics.

Consumer preferences in groups A, B and C were discussed in sections 3 and 4. The two firms' market shares in each consumer group follow straight from consumer preferences, summarized in table 1 and the distribution of demand F. Taking all consumer groups together we can compute the firms' payoffs as functions of the strategies p_1 and p_2 and the degenerate belief p_e:

$$\pi_1 = p_1 \times \begin{cases} \alpha_B \frac{\omega - p_1 + p_2}{\omega} + \alpha_C \frac{\eta - p_1 + p_e}{\eta} & \text{if } \; p_1 > p_2 \text{ and } p_e \\ \alpha_B \frac{\omega - p_1 + p_2}{\omega} + \alpha_C & \text{if } \; p_1 > p_2 \text{ and } p_1 \leq p_e \\ 1 & \text{if } \; p_1 \leq p_2 \end{cases} \tag{19}$$

$$\pi_2 = p_2 \times \begin{cases} \alpha_A + \alpha_B \frac{p_1 - p_2}{\omega} + \alpha_C \frac{p_1 - p_e}{\eta} & \text{if } \; p_2 \leq p_e < p_1 \\ \alpha_A + \alpha_B \frac{p_1 - p_2}{\omega} & \text{if } \; p_1 > p_2 \text{ and } p_1 \leq p_e \\ 0 & \text{if } \; p_2 \geq p_1 \end{cases} \tag{20}$$

The first lines of (19) and (20) are of primary interest, when firm 1 charges a higher price then firm 2 and consumers belief that firm 2 is offering a lower price. The second lines apply when consumers belief p_2 is larger than p_1 while the opposite is true. Lines 3 refer to the case when firm 1 undercuts firm 2.

The following proposition defines a perfect Bayesian equilibrium in pure strategies and the conditions under which it exists.

Proposition 4 *When consumers face no search- or switching costs (group A), switching cost (group B) or search cost (group C), and the condition*

$$\left(1 - \alpha_B - \alpha_C\right)\left(\alpha_B \eta + \alpha_C \omega\right)\left(\alpha_C \omega + 5\alpha_B \eta\right) \leq \alpha_B^2 \eta^2 \left(\alpha_B + \alpha_C\right)^2 \tag{21}$$

holds,

$$p_1^* = \frac{\alpha_B(1+\alpha_B+\alpha_C)\eta+\alpha_C\omega}{(3\alpha_B\eta+\alpha_C\omega)(\alpha_B\eta+\alpha_C\omega)}\omega\eta \text{ and} \tag{22}$$

$$p_2^* = \frac{2-\alpha_B-\alpha_C}{3\alpha_B\eta+\alpha_C\omega}\omega\eta \tag{23}$$

are unique pure strategy perfect Bayesian equilibrium price strategies.

Proof. By the same logic as in the proof of proposition 1, an assessment where $p_1 \leq p_2$ is never an equilibrium. Firm 1 would always prefer $p_1 = p_2$ to $p_1 < p_2$, and firm 2 would prefer to undercut any profile with $p_1 = p_2$ or choose a $p_2 >> p_1$ for a low p_1 and increase its profit discontinuously. In a PBE consumer beliefs must be consistent with the selected strategies, which rules out the case when $p_e > p_1$.

Hence when $p_1 > p_2$ and p_e, the candidate equilibrium assessment is derived from first order conditions using the first lines of (19) and (20)

$$\alpha_B\frac{\omega-2p_1+p_2}{\omega}+\alpha_C\frac{\eta-2p_1+p_e}{\eta} = 0 \tag{24}$$

$$(1-\alpha_B-\alpha_C)+\alpha_B\frac{p_1-2p_2}{\omega}+\alpha_C\frac{p_1-p_e}{\eta} = 0 \tag{25}$$

together with the consistency requirement $p_2 = p_e$. Solving these together yields the equilibrium candidate (22) and (23). As the payoff functions are continuous and strictly concave, when $p_1 > p_2$ and p_e, the solution is unique when these conditions hold.

To verify if this is truly an equilibrium, we must consider potential deviation by firm 1 and 2. The profits associated with the candidate strategy profile are respectively,

$$\pi_1^* = \frac{(\alpha_B\eta(\alpha_B+\alpha_C+1)+\alpha_C\omega)^2}{(3\alpha_B\eta+\alpha_C\omega)^2(\alpha_B\eta+\alpha_C\omega)}\omega\eta$$

$$\pi_2^* = \frac{\alpha_B(2-\alpha_B-\alpha_C)^2}{(3\alpha_B\eta+\alpha_C\omega)^2}\omega\eta^2.$$

Firm 2 would never benefit by deviating. The candidate solution is the unique best response given $p_1 > p_2$ and p_e and choosing $p_2 \geq p_1$ would yield zero profits. Firm 1, on the other hand, might benefit by undercutting p_2 slightly, and steal all A consumers and those among C consumers that search. When firm 1's deviates and chooses $p_1 = p_2 - \varepsilon$ while $p_2 = p_2^*$ its payoff is

$$\pi_1^d = \frac{2 - \alpha_B - \alpha_C}{3\alpha_B \eta + \alpha_C \omega} \omega \eta$$

when $\varepsilon \to 0$. The sign of $\pi_1^d - \pi_1^*$ equals the sign of $\frac{3\alpha_B \eta + \alpha_C \omega}{\omega \eta} \left(\pi_1^d - \pi_1^*\right)$ or the expression

$$\left(1 - \alpha_B - \alpha_C\right)\left(\alpha_B \eta + \alpha_C \omega\right)\left(\alpha_C \omega + 5\alpha_B \eta\right) - \alpha_B^2 \eta^2 \left(\alpha_B + \alpha_C\right)^2$$

which is negative when (21) holds. Hence, whenever (21) holds firm1 has no interest in deviating from (p_1^*, p_2^*) and neither does firm 2, so the assessment (including the belief $p_e = p_2^*$) is a PBE. If, however, (21) does not hold no equilibrium in pure strategies exists. Then firm 1 would prefer to undercut firm p_2, starting an infinite cycle of undercutting as described earlier. ■

Before we look at the comparative statics of this equilibrium, a few words about condition (21) are in order. If the condition does not hold, firm 1 would prefer to undercut firm 2's price and thereby steal the complete market from firm 2. Analogous to the condition in proposition 1, it defines the maximum $\alpha_A = 1 - \alpha_B - \alpha_C$ that maintains the balance between the asymmetric pricing strategies of the incumbent and the entrant. The condition is much more complicated than the previous one, since non-shoppers can either belong to groups B or C. The example shown in figure 1 gives a rough idea, for the case when $\omega = \eta = 1$. The shaded area represents all combinations of α_B and α_C that satisfy the condition. It is bound below by condition (21) and above by the the fact that the α's must sum up to one. The lower bound is close to being linear, going from $\alpha_B = \frac{3\sqrt{5}-5}{2}$ when $\alpha_C = 0$ and up to $\alpha_C = 1$ when $\alpha_B = 0$. These two extremes are consistent with the results in the previous sections. The maximum value for α_B is simply $1 - \alpha_A$ in the condition for the existence of Nash equilibrium when there are no search-cost-constrained consumers of type C. The fact that α_C must be as high as 1 when $\alpha_B = 0$ is simply a reminder of the non-existence result from section 4.

If we assume that condition (21) holds, an equilibrium exists with prices (22)

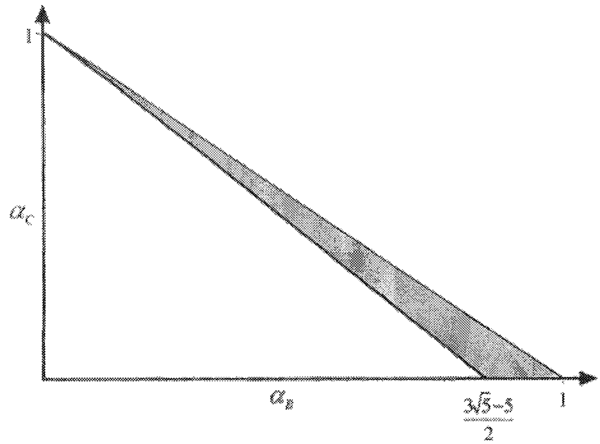

Figure 1: An example of the range of α_B and α_C that facilitates existence of a pure strategy equilibrium

and (23) and corresponding market shares

$$s_1^* = \frac{\alpha_B(1+\alpha_B+\alpha_C)\eta+\alpha_C\omega}{3\alpha_B\eta+\alpha_C\omega} \text{ and} \tag{26}$$

$$s_2^* = \alpha_B\frac{2-\alpha_B-\alpha_C}{3\alpha_B\eta+\alpha_C\omega}\eta. \tag{27}$$

Prices and market shares are affected by all four variables: the share of consumers with positive switching cost α_B and search cost α_C, and the size of the switching cost ω and the search cost η.

Some important comparative statics results are listed in the following corollaries. The proofs follow trivially from the respective partial derivatives, which are listed in the appendix.

Corollary 3 *When consumers face no search- or switching costs (group A), switching cost (group B) or search cost (group C) and condition (21) holds, a slight decrease in α_B (met by a corresponding increase in α_A):*

1. *has an indetermined effect on the incumbent's price*

2. *decreases the entrants price (unless the switching the cost is much higher than the search cost, $\omega \geq 3\frac{2+\alpha_C}{a_C}\eta$)*

3. *leads to a decrease in the incumbents market share (unless the switching cost is much higher than the search cost, $\omega \geq 3\frac{\alpha_B^2}{(2-2\alpha_B-\alpha_C)\alpha_C}\eta$).*

Corollary 4 *When consumers face no search- or switching costs (group A), switching cost (group B) or search cost (group C) and condition (21) holds, a slight decrease in α_C (met by a corresponding increase in α_A) leads to :*

1. *an increase in both firms' prices*

2. *a decrease in the incumbent's market share.*

Recall that, when a zero mass of consumers had search costs, an increase in α_A led to an increase in both firms prices and a decrease in the incumbents market share (corollary 1), or qualitatively the same result as in corollary 4 when the number of shoppers increases at the expense of search-cost consumers. When α_A increases at the expence of α_B however, the effect are less clear cut. Unless the switching cost is very high relative to the search cost, it would probably have qualitatively similar results.

Corollary 5 *When consumers face no search- or switching costs (group A), switching cost (group B) or search cost (group C) and condition (21) holds, a slight decrease in the switching cost ω leads to:*

1. *a decrease in both firms' prices*

2. *a decrease in the incumbent's market share.*

Interestingly, when C consumers were not included in section 3, market shares turned out to be independent of the switching cost (see corollary 2). When we allow for a positive share of C consumers this changes so that the incumbent's market share shrinks when the switching cost decreases. This is caused by the fact that the incumbent also faces consumers with search costs that are kept constant. Hence, its price response is smaller than if those search-cost consumers were not around.

Corollary 6 *When consumers face no search- or switching costs (group A), switching costs (group B) or search costs (group C) and condition (21) holds, a slight decrease in the search cost η leads to:*

1. *a decrease in both firms' prices*

2. an increase in the incumbent's market share.

While both prices decrease in response of a decrease in search cost, the relative change is quite different from when the switching cost goes down. It seems counter-intuitive that the incumbent's market share increases if the search cost goes down, but it is not. The entrant's price decreases by less than the incumbent's price as a result of a decrease in search cost. This is because C consumers are not directly affected by changes in p_2 as it is only observable if a search takes place.

6 Conclusions

This simple model provides a few interesting observations, that seem quite important for the policy debate, if the results hold under more general conditions. Two stand out as most important. First, the rate of switching can be a bad measure of market performance. For certain distributions of search and switching costs, especially with few search-cost consumer, firms' market shares are more or less unaffected by changes in search costs. A decrease in switching costs affects prices, but for the benefit of all consumers and not only those who choose to switch. Second, a decrease in search costs is likely to be primarily in the interest of those consumers that do not wish to search, as the incumbents price decreases by more than the entrant's when the search cost decreases. Both these results suggest that consumers are facing a free-rider problem, as everyone benefits from a shift in the distribution of consumers towards an increased number of shoppers, while becoming an active consumer may be costly for the individual.

Further research is required to test the generality of these results. Several different routes where considered while this paper was in preparation, including multiple entrants, downwards sloping demand, and multiple periods. All these led to complications that rendered closed form solution impossible to derive or extremely difficult to interpret. A natural extension is therefore to analyze more realistic extensions of this model using numerical methods.

Appendix - Comparative statics on the equilibrium of proposition 4

The following partial derivatives are taken from equilibrium prices (22), (23) and market shares (26) and (27) as defined in section 5.

The effect of α_B

$$\frac{\partial p_1^*}{\partial \alpha_B} = \frac{-3\left(\alpha_B\eta+\alpha_C\omega\right)^2+2\alpha_B\alpha_C\left(\alpha_C\omega+2\alpha_B\eta\right)\omega+\alpha_C\left(-3\alpha_B^2\eta^2+\alpha_C^2\omega^2\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2\left(\alpha_B\eta+\alpha_C\omega\right)^2}\eta^2\omega \gtreqless 0$$

$$\frac{\partial p_2^*}{\partial \alpha_B} = \frac{\alpha_C\left(3\eta-\omega\right)+6\eta}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\omega\eta > 0 \text{ if } \omega < 3\frac{2+\alpha_C}{a_C}\eta$$

$$\frac{\partial s_1^*}{\partial \alpha_B} = \frac{3\alpha_B^2\eta-\alpha_C\omega\left(2-2\alpha_B-\alpha_C\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta > 0 \text{ if } \omega < 3\frac{\alpha_B^2}{\left(2-2\alpha_B-\alpha_C\right)\alpha_C}\eta$$

$$\frac{\partial s_2^*}{\partial \alpha_B} = -\frac{3\alpha_B^2\eta+2\alpha_B\alpha_C\omega+\alpha_C^2\omega-2\alpha_C\omega}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta < 0 \text{ if } \omega < 3\frac{\alpha_B^2}{\left(2-2\alpha_B-\alpha_C\right)\alpha_C}\eta$$

The effect of α_C

$$\frac{\partial p_1^*}{\partial \alpha_C} = -\frac{\alpha_B^2\eta^2\left(\left(1+4\alpha_B\right)\omega-3\alpha_B\eta\right)+\alpha_B\alpha_C\omega^2\eta\left(\alpha_C+2\alpha_B+2\right)+\alpha_C^2\omega^3}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2\left(\alpha_B\eta+\alpha_C\omega\right)^2}\omega\eta < 0$$

$$\frac{\partial p_2^*}{\partial \alpha_C} = -\frac{3\alpha_B\eta+\omega\left(2-\alpha_B\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\omega\eta < 0$$

$$\frac{\partial s_1^*}{\partial \alpha_C} = \alpha_B\frac{3\alpha_B\eta+\omega\left(2-\alpha_B\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta > 0$$

$$\frac{\partial s_2^*}{\partial \alpha_C} = \alpha_B\frac{-3\alpha_B\eta-\omega\left(2-\alpha_B\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta < 0$$

The effect of ω

$$\frac{\partial p_1^*}{\partial \omega} = \alpha_B\frac{3\alpha_B\alpha_C\left(\eta\alpha_B+2\omega\right)\eta+\left(3-\alpha_B-\alpha_C\right)\alpha_C^2\omega^2+3\left(1+\alpha_B\right)\alpha_B^2\eta^2}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2\left(\alpha_B\eta+\alpha_C\omega\right)^2}\eta^2 > 0$$

$$\frac{\partial p_2^*}{\partial \omega} = 3\frac{\alpha_B\left(2-\alpha_B-\alpha_C\right)}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta^2 > 0$$

$$\frac{\partial s_1^*}{\partial \omega} = \alpha_B\alpha_C\frac{2-\alpha_B-\alpha_C}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta > 0$$

$$\frac{\partial s_2^*}{\partial \omega} = -\alpha_B\alpha_C\frac{2-\alpha_B-\alpha_C}{\left(3\alpha_B\eta+\alpha_C\omega\right)^2}\eta < 0$$

The effect of η

$$\frac{\partial p_1^*}{\partial \eta} = \alpha_C \frac{\alpha_B^2 (1+4\alpha_B+4\alpha_C)\eta^2 + 2\alpha_B\alpha_C(\alpha_B+1)\omega\eta + \alpha_C^2(2\alpha_B\eta+\omega)\omega}{(3\alpha_B\eta+\alpha_C\omega)^2(\alpha_B\eta+\alpha_C\omega)^2}\omega^2 > 0$$

$$\frac{\partial p_2^*}{\partial \eta} = \frac{\alpha_C(2-\alpha_B-\alpha_C)}{(3\alpha_B\eta+\alpha_C\omega)^2}\omega^2 > 0$$

$$\frac{\partial s_1^*}{\partial \eta} = -\alpha_B\alpha_C\frac{2-\alpha_B-\alpha_C}{(3\alpha_B\eta+\alpha_C\omega)^2}\omega < 0$$

$$\frac{\partial s_2^*}{\partial \eta} = \alpha_B\alpha_C\frac{2-\alpha_B-\alpha_C}{(3\alpha_B\eta+\alpha_C\omega)^2}\omega > 0$$

The first sign (of $\frac{\partial p_1}{\partial \alpha_C}$) is not obvious, but follows from the fact that $\frac{\partial p_2^*}{\partial \alpha_C} < 0$ and $\frac{\partial s_1^*}{\partial \alpha_C} > 0$. Firm 1's market share can only be increasing in α_C if its price is decreasing relative to p_2, which is decreasing.

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Chapter 3

Power to Cheat?

Power to Cheat?*

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Abstract

Consider a vertically integrated electricity company that provides regulated local network services while being active in a deregulated but imperfectly competitive retail market for electricity. Its total costs are known, both to the regulator and its competitor, while the distribution between the two costs is private knowledge of the incumbent. The firm has a natural incentive to overstate its costs for the network services to receive a higher regulated price. However, since total costs of both operations are known, a claim of high network costs signals low retail costs. When firms compete in prices, which are strategic compliments, the integrated firm would like its competitor to belief that retail costs are high as well. The regulator, through a combination of price incentives and monitoring, can utilize this trade-off and induce an information-revealing separating equilibrium in which the incumbent claims its true type. The optimal combination of price incentives and monitoring and the conditions under which such a separating equilibrium is preferred to a pooling equilibrium are derived.

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1 Introduction

The waive of deregulation that has swept across the world economies, leaving few industries untouched. Among the most recent developments is the partial deregulation of network industries, through separation of operations. In industries like electricity and gas, for instance, the networks are usually considered to be natural monopolies and therefore kept regulated, while the services provided via the network are deregulated. The electricity supply industry, which we use as the primary example throughout this paper, is commonly separating into four distinct product levels: production or generation, transmission via high-voltage power lines, low-voltage local distribution, and retailing. The electricity grid used for transmission and distribution is, for all practical purposes, a natural monopoly and given a status as essential facilities for the provision of the deregulated services.

In the pre-deregulation era most electricity industries were dominated by large vertically integrated, and usually publicly owned, power companies or utilities. An important feature of any deregulation scheme is a formal and effective separation of transmission from generation, introducing an independent system operator. Restructuring has not been as widespread when it comes to local distribution and retailing, and integrated incumbents are usually allowed to continue to provide both services. Formal requirements for separation, in one form or another, are common but rather imperfect in practice. In Norway, and initially in England and Wales, a separation of accounts was considered sufficient. In the United Kingdom the requirements were strengthened by the Utilities Act of 2000, prohibiting a single company to hold both distribution (local network) and supply (retail) licenses. Also in Sweden, a formal separation of the operations in different legal entities is required, but these entities can still have the same owner and be part of the same group of companies, and occasionally also share CEO's and personnel. The EU-directive for the electricity market, specifies a separation of production, transmission and distribution, where distribution is defined as "the transport of electricity on medium-voltage and low-voltage distribution systems with a view to its delivery to customers" (Directive 96/92/EC). This illustrates how the directive does not clearly distinguish between retailing and local network services.

The existence of vertically integrated firms operating as regulated monopolies in distribution while competing with other retailers, is a cause for concern by regulators and competition authorities alike. Cross-subsidization is one problem that has been recognized for a long time both in the academic literature and among practitioners. Two early contributions are Averch & Johnson (1962) and Wellisz (1963), who showed that rate-of-return regulation incites firms to overproduce the competitive service in order to expand their capital base. A substantial literature on cross-subsidization has been developed since then. Faulhaber (1975) explicitly defined subsidy-free pricing and presented two tests for cross-subsidization. The incremental cost test is satisfied if the revenue from any service is greater than or equal to the incremental cost of providing the service, and guarantees that the service does not receive a cross-subsidy. The stand-alone cost test is satisfied if the revenue from a service is less than or equal to the cost of providing that service independently and guarantees that the service does not provide a cross-subsidy. The stand-alone test was later modified by Sharkey & Telser (1978). Brock (1983) explicitly accounts for fixed and common costs faced by a rate-of-return regulated firm and showed that regulated firms are not more likely to engage in predatory cross-subsidization than unregulated firms. Braeutigam & Panzar (1989) arrived at results similar to Averch & Johnson (1962), but without relying on the assumptions that the regulated rate-of-return exceeds the cost of capital. Palmer ((1989*a*, 1989*b*, 1991, 1992)) further developed the tests for cross-subsidization. Brennan (1990) used the incremental and stand-alone cost as two polar cases of a more general set of regulatory regimes and studies different cross-subsidization tactics. He finds that these tactics lead to higher prices in the regulated market and inefficient production in the unregulated market. To some extent he also discusses the effects of strategic interactions between firms.

One aspect that is almost entirely neglected, in this rather extensive literature, is the effect of imperfect competition and strategic interaction in the unregulated market on incentives to cross-subsidize. At the same time, retail electricity markets bear little resemblance to perfectly competitive markets as discussed at length in chapter 1. On the contrary, it seems reasonable to assume that unregulated retail electricity markets are characterized by imperfect competition. In particular we assume that the firms compete in prices, when consumers face switching costs, as analyzed in more detail in chapter 2.

Here we develop a model where an incumbent diversified firm operates in two vertically related markets: a regulated network market and an unregulated retail market. The incumbent's cost structure, i.e., the distribution of costs between operations is private information of the firm, while its aggregate costs are known to all.

Cost reporting to a regulatory authority can be interpreted as a signal of the true cost of operating the network. But implicit in the signal is also a claim regarding its costs of providing the unregulated service. For an established (partially) deregulated market this form of signalling can take place repeatedly, as a diversified incumbent is constantly under regulatory scrutiny. A more pertinent example, though, is the once-and-for-all event when new regulatory rules are implemented, that call for a separation of accounts or even a more formal legal and managerial separation. It is reasonable to expect an incumbent to have superior information about its true cost structure, while the process of cost analysis only reveals an imperfect picture.

A firm might want to report high costs for the regulated service in order to increase the regulated network price. But that amounts to claiming to have relatively low costs for the unregulated service. But, as prices are strategic complements, this goes against its interests as the competition lowers its price, if the signal is credible. It is precisely this trade-off facing the incumbent firm, that the regulator can take advantage off. We show that a regulator can induce a separating equilibrium in which the incumbent firm reports its true costs, by a combination of pricing incentives and monitoring. Thereby the expected network price is reduced at the same time as the information problem in the deregulated market is eliminated. The alternative is a pooling equilibrium, in which the incumbent claims to have high costs for the regulated service irrespective of its cost structure.

The practice of manipulating accounts or shifting costs is closely related to cross-subsidization, even though it may not fulfill the formal definitions of the latter (as defined by Faulhaber, 1975). Imperfect competition in the unregulated market makes it possible that both services meet the incremental cost test and receive revenues greater than the incremental cost of producing the service.

We do not address the question whether an incumbent firm should be allowed to remain vertically integrated or diversity into other markets. We assume that the diversification has taken place, or rather that a previously integrated and regulated market is only partially deregulated. Different aspects of diversification policies are analyzed by Brennan (1990), Brennan & Palmer (1994), Braeutigam & Panzar (1989), Braeutigam (1993) and Sappington (2003) among others.

The remainder of this paper is organized as follows. In section 2 the full-information benchmark model is developed. In section 3 we introduce asymmetric information and derive pooling and a separating equilibrium. The optimal regulation, given that the separating equilibrium is preferable, is derived in section 4 and the choice between the two types of equilibria is also discussed. Section 5 concludes the paper.

2 Benchmark model

Consider the following model of a partially regulated electricity industry, which has just been reformed, so that competition is allowed in retailing, the downstream market, while network services continue to be the incumbent utility's responsibility. To keep things simple we assume that a single entrant, firm 2, is committed to participate in retailing.[1] The incumbent, firm 1, continues to run its retail operation as well as the network service. It is required to separate its accounts for the two operations, for the sake of transparency. To simplify we assume that all fixed costs and variable costs that can be verified to belong to either operation are zero. What remains is the part of the incumbent's variable costs that can not easily be allocated to either operation, using publicly available information. We call these *disputable costs.*

Marginal (disputable) costs are assumed to be constant. Firm 1's marginal cost of providing retail services is c_1 and c_n for network services. Firm 2's marginal cost is c_2. Due to the normalization of costs, c_2 should be interpreted as firm 2's variable costs in excess of firm 1's undisputed costs.

Infinitesimal consumers are uniformly distributed along the unit interval. Each consumer has a unit demand up to the reservation price s, which is sufficiently high so the market is always covered. By this simple construction, aggregate demand is constant and equal to unity. All consumers have a relationship with the incumbent and incur a switching cost σ if they choose firm 2 as their supplier. When purchasing from the incumbent a consumer pays the incumbent's price for electricity p_1 plus the network charge p_n. When purchasing from an entrant, a consumer pays the entrant's price p_2, the network charge p_n and incurs a switching cost of σ. Consumers have different values of σ, according to their location on the unit interval. More specifically, σ is linearly increasing from 0 on one end to σ_h on the other. Firms are unable to detect individual values of σ, and thereby target consumer, but know the distribution of σ.

[1] Adding more firms would complicate the analysis, while naturally reduce the scope for market power. We briefly discuss the case when market power is negligiable later on.

Assumption 1 $\sigma \sim U[0, \sigma_h]$.

Consumers are utility maximizers. Let u_1 be the net value of purchasing the service from the incumbent and u_2 when purchasing from the entrant. More specifically

$$u_1(p_1, p_n) = s - p_1 - p_n \text{ and} \tag{1}$$
$$u_2(p_2, p_n, \sigma) = s - p_2 - p_n - \sigma. \tag{2}$$

The marginal consumer, or the consumer that is indifferent between purchasing from firm 1 and 2 must have $u_1 = u_2$. This implies that his switching cost, $\widetilde{\sigma}$, is equal to the difference in the retail prices, $\widetilde{\sigma} = p_1 - p_2$. The incumbent's demand is equal to the share of consumers with $\sigma \geq \widetilde{\sigma} = p_1 - p_2$, namely

$$q_1(p_1, p_2) = \frac{\sigma_h - (p_1 - p_2)}{\sigma_h}. \tag{3}$$

All consumers with $\sigma < \widetilde{\sigma}$ purchase from firm 2, which has the demand function

$$q_2(p_1, p_2) = \frac{p_1 - p_2}{\sigma_h}. \tag{4}$$

Both firm face a demand function, which is downwards sloping in own price and increasing in the rivals price, even though aggregate demand is constant.

Firm 1's profit is

$$\begin{aligned} \pi^1(p_1, p_2, p_n) &= (p_n - c_n) + (p_1 - c_1)\, q_1(p_1, p_2) \text{ or} \\ &= (p_n - c_n) + (p_1 - c_1)\frac{\sigma_h - (p_1 - p_2)}{\sigma_h}. \end{aligned} \tag{5}$$

The first term on the right represents net revenue from the network service while the second term is the net income from the retail service. Note that the total quantity of network services is one, due to the simple demand assumptions. Firm 2 is only active in the retail market and has a simpler expression for its profit:

$$\begin{aligned} \pi^2(p_1, p_2) &= (p_2 - c_2)\, q_2(p_{1,}p_2) \text{ or} \\ &= (p_2 - c_2)\frac{p_1 - p_2}{\sigma_h}. \end{aligned} \tag{6}$$

Assume, for now, that all cost parameters are fully disclosed and that p_n is

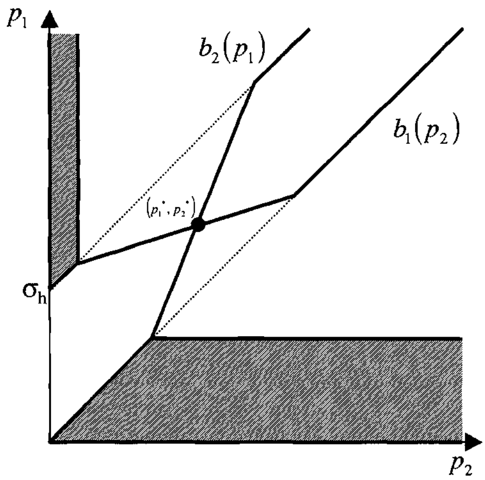

Figure 1: Best-response correspondences and equilibrium prices in the benchmark case

exogenously determined by regulation authorities (the regulator). The firms choose p_1 and p_2 simultaneously from $\mathbb{R}_+$. From first order conditions we can derive each firm's best response correspondence,

$$b_1(p_2) = \begin{cases} [p_2 + \sigma_h, \infty] & \text{if} \quad p_2 \leq c_1 - \sigma_h \\ \frac{p_2 + c_1 + \sigma_h}{2} & \text{if} \quad c_1 - \sigma_h < p_2 \leq c_1 + \sigma_h \\ p_2 & \text{if} \quad p_2 > c_1 + \sigma_h \end{cases}, \tag{7}$$

$$b_2(p_1) = \begin{cases} [p_1, \infty] & \text{if} \quad p_1 \leq c_2 \\ \frac{p_1 + c_2}{2} & \text{if} \quad c_2 < p_1 \leq c_2 + 2\sigma_h \\ p_1 - \sigma_h & \text{if} \quad p_1 > c_2 + 2\sigma_h \end{cases}. \tag{8}$$

The first row of (7) describes the case when p_2 is so low, that firm 1 can not attain positive market share without charging a price below marginal cost and is indifferent between any feasible choice of prices for which it will not sell anything and receive zero profit. The second line refers to the interior case, where neither price is sufficiently low to price the other firm out of the market. The third line refers to the situation when firm 2 sets a price so high that it prices itself out of the market. The best response correspondence for firm 2 is analogous and needs not to be explained in detail.

Figure 1 provides an example of both firm's best response functions with an interior intersection. The area between the two diagonal lines represents price pairs that facilitate positive market shares for both firms. When a rival charges a sufficiently high price, the best response is to slightly undercut his price. This means, to stay ε below the respective dotted line. If the competitor charges sufficiently low price, a firm is unable to earn positive profits and any price larger than cost is a best response. This is represented by the grey areas in the figure. For moderate prices however, the best response correspondences are identical to those of a simple linear Bertrand model with product differentiation.

Throughout the paper we will focus on the case when there exists an interior solution, i.e., when both firms have positive market shares in equilibrium. This implies the following parameter restriction.

Assumption 2 $c_1 - 2\sigma_h < c_2 < c_1 + \sigma_h$

Under assumption 2 we can limit our search for a Nash equilibria to the interior segments of the best-response correspondences. We will, occasionally, refer to these interior segments as the best-response functions, despite our stated concern above. A fixed point of these best-response functions defines the equilibrium strategies

$$p_1^* = \frac{2c_1 + c_2 + 2\sigma_h}{3}, \tag{9}$$

$$p_2^* = \frac{c_1 + 2c_2 + \sigma_h}{3}, \tag{10}$$

which translate into the corresponding quantities

$$q_1^* = \frac{c_2 - c_1 + 2\sigma_h}{3\sigma_h}, \tag{11}$$

$$q_2^* = \frac{c_1 - c_2 + \sigma_h}{3\sigma_h}, \tag{12}$$

and equilibrium profits

$$\pi^{1*} = p_n - c_n + \frac{1}{9\sigma_h}\left(c_1 - c_2 - 2\sigma_h\right)^2, \tag{13}$$

$$\pi^{2*} = \frac{1}{9\sigma_h}\left(c_2 - c_1 - \sigma_h\right)^2. \tag{14}$$

Existence and uniqueness follows straight from assumption 2 and the slope of the linear response functions.[2]

This equilibrium outcome has several interesting characteristics that fit well to retail markets for electricity, e.g., asymmetric market shares, price dispersion and limited scope of consumer switching. See chapters 1 and 2 for more details and extensions. Here we would like to extend this simple model to allow for an important information problem, which can give rise to cross-subsidization and unnecessarily high network prices. Namely, when the incumbent firm has exclusive information about how its costs are divided between its two operations.

In the standard switching cost literature (see for instance Klemperer (1987*a*, 1987*b*, 1995)) there is an initial period in which the firms compete for market shares and a second period in which the locked-in consumers are exploited. The initial effect with bargains for the consumers is not present in our one-period model, since all consumers are assumed to be committed to the incumbent from the beginning.

3 Shifting costs

It is common, in the regulation literature, to assume that firms that are being regulated have better information about their technology than does the regulator (see Laffont & Tirole (1993)).Typically, a regulator is able to observe total costs while the effort put on reducing costs is only known to the firm. In a similar spirit, we assume that total disputable costs C are observed and verifiable by all, while only firm 1 knows the true cost parameters c_1 and c_n. Firm 2 and the regulator know, however, the sum of the two costs. Since aggregate demand is 1 and the incumbent has previously enjoyed a monopoly in both markets, the cost parameters sum to up to $C = c_n + c_1$. Firm 2's variable retail cost, c_2, is still known to both players.

Firm 1 can be of two types, with respect to its cost structure. With probability ρ it has high network costs and low retail costs and with probability $(1-\rho)$ its network costs are low and retail costs high. We will call the first a high-type, h, and the second a low-type, l, referring to the network cost. The network and retail costs of type θ are denoted as c_n^θ and c_1^θ respectively. Note, that since the retail cost is lower for type h than for type l, we have $c_1^h < c_1^\ell$. Below we will frequently refer to firm 1's unconditional expected retail cost as $E(c_1) = \rho c_1^h + (1-\rho) c_1^l$

Since the total cost C is the same no matter what type firm 1 really is, we

[2]Uniqueness is far from assured if we drop assumption 2. If the parameter values are such that either firm has zero market share, there is a continuum of equilibria.

must have that $c_n^h + c_1^h = c_n^l + c_1^l$. Further more, this implies that the difference between the network costs of type h and l is equal to the difference between the two types' retail costs. To simplify notation we refer to this difference as Δ, i.e., $\Delta = c_1^h - c_1^h = c_n^l - c_n^l$.[3]

We concentrate on the case where an interior solution can generally be expected, that is to say, when both firms have positive market shares in equilibrium. If we want that to hold for both types of firm 1, we need to refine assumption 2. The intuition behind the following assumption will be given later on, when we have defined market equilibria.

Assumption 3

$$\frac{3c_1^\ell - E(c_1)}{2} - 2\sigma_h < c_2 < \frac{3c_1^h - E(c_1)}{2} + \sigma_h.$$

The common practice in regulating of a firm, which also operates in a non-regulated market, is a two step process (see for instance Braeutigam, 1980). First, those costs that unambiguously can be attributed to either service are assigned to that service. Second, those costs that remain and are disputed, are allocated to each service according to some arbitrary allocation formula. The result of such cost analysis depends, to a large extent, on the regulated firms accounting procedures and its ability to shift costs between different operations. In the following we refer to the cost distribution, as presented in the incumbent's accounts as a signal sent to the regulator. The signal is then revealed to the entrant firm through disclosure of the cost analysis.

In anticipation of the firms signal, the regulator specifies a pricing scheme, which depends on the signal sent. The incumbent firm can choose between two contracts (h, p_n^h) or (ℓ, p_n^l). If it claims to be of type h it gets to charge p_n^h for its network services and if it says it is of type l the network price is restricted to p_n^l. We choose to represent the pricing scheme by an affine function,

$$p_n\left(\widehat{\theta}\right) = \alpha - \beta(c_n^h - c_n^{\widehat{\theta}}), \tag{15}$$

where $c_n^{\widehat{\theta}}$ is the network cost of a type $\widehat{\theta}$ firm, $\widehat{\theta}$ being the claimed type. Hence, a firm claiming to have high retail costs will get a network price equal to α and a firm

[3] In an earlier version of the paper we used an arbitrary market share for firm1 as a benchmark, without altering the results in any way.

claiming to have low network costs will be able to charge $\alpha - \beta\Delta$.

The regulator is also able to monitor claims made by the incumbent firm through an audit. The regulator sets the monitoring intensity, which translates into the probability of discovering the true type of the incumbent so that it can be verified in court. It also determines a fine that the incumbent will have to pay if it is proven to be untruthful in its claim, i.e., its signal is revealed to be different from its type. For now, we let intensity of monitoring, m, and the size of the penalty, f, be exogenous and independent of the signal sent.

Endogenous determination of the network price scheme, the monitoring intensity and the amount of the fine is postponed until section 4. In the remainder of this section we consider the firms' interaction for a given set of regulatory and monitoring parameters. To simplify the exposition we use the expected monetary loss when exposed giving a false signal, ε, to summarize the monitoring procedure. The expected loss equals the probability of detection $\gamma(m, \Delta)$, a function of monitoring intensity and the difference between the types' costs, times the fine, f.

3.1 The game

Now let the model derived in the previous section be the last stage in a three stage game with two players: firm 1 and firm 2. Even though the game is essentially a game of incomplete information we follow the Harsanyi tradition of transforming the game into a game of complete, but imperfect, information. In the first stage (stage 0) nature selects a realization of θ and with probability ρ firm 1 is of type h and with probability $1 - \rho$ it is of type l, $\rho \in (0, 1)$. The realization is only revealed to firm 1 and not firm 2 (nor the regulator). In stage 1, firm 1 makes a claim, $\widehat{\theta}$, about its type, θ. In stage 2 both firms, having observed $\widehat{\theta}$ and the associated claimed cost structure, $\widehat{c} = (\widehat{c}_1, \widehat{c}_n)$, choose their retail prices, p_1 and p_2, simultaneously.

Firm 1 has two behavioral strategies. The first is a mapping from the type space to the signal space, which are identical by construction, $\phi : \Theta \rightarrow \Theta$, where $\widehat{\theta} = \phi(\theta)$. The second strategy is a mapping from the space of the current history of play, consisting of the correct and the claimed types, to a space of feasible prices, $\varphi_1 : \Theta^2 \rightarrow \mathbb{R}_+$, where $p_1 = \varphi_1\left(\theta, \widehat{\theta}\right)$. Firm 2's strategy is a mapping from the signal space (type space) to the price space, $\varphi_2 : \Theta \rightarrow \mathbb{R}_+$, where $p_2 = \varphi_1\left(\widehat{\theta}\right)$.

Firm 1's payoff is a function of its own strategies (and the competitors strategy which is outside his control) and conditional on its type.

$$\pi_1\left(p_1, \widehat{\theta}|\theta\right) = \alpha - \beta(c_n^h - \widehat{c}_n^\theta) - c_n - \varepsilon \times I_{\widehat{\theta}\neq\theta} + (p_1 - c_1)\frac{\sigma_h + p_2 - p_1}{\sigma_h}, \tag{16}$$

where $I_{\widehat{\theta}\neq\theta}$ is a binary variable, taking the value 1 if $\widehat{\theta} \neq \theta$ and 0 otherwise.

The first three terms on the right hand side of (16) represent the net income firm 1 has from the network service, as specified in (15). The forth is the expected loss of shifting costs (only applies if the signal is untruthful), and the fifth shows net income from the retail service, as specified in (5).

Firm 2's payoff originates solely from its sales in the retail market. Firm 2 is unaware of the correct cost structure of firm 1. Being risk neutral, it maximizes its expected profits conditional on the signal sent by firm 1. Firm 2's belief is characterized by $\omega(\widehat{\theta})$, the probability that firm 1 is of type h conditional on firm 1's signal $\widehat{\theta}$. Expected profit is then given by

$$E(\pi_2) = \omega(\widehat{\theta})\,(p_2 - c_2)\frac{p_1^h - p_2}{\sigma_h} + \left(1 - \omega(\widehat{\theta})\right)(p_2 - c_2)\frac{p_1^l - p_2}{\sigma_h} \tag{17}$$

where p_1^h and p_1^l constitute particular price strategies for a high and low type firm 1 respectively.

We use perfect Bayesian equilibrium to find pure strategy equilibria in this game. Its simple structure allows for a simplified version of the general definition.

Definition 1 *For the defined game, a strategy profile $\{\phi(\cdot), \varphi_1(\cdot), \varphi_2(\cdot)\}$ and a belief $\omega(\cdot)$, jointly referred to as an assessment, constitute a perfect Bayesian equilibrium (PBE) if the following conditions are fulfilled.*

1. *For any given belief, $\omega(\cdot)$, (16) and (17) are simultaneously maximized with respect to ϕ and φ_1 in the first case and φ_2 in the second.*

2. *Firm 2's beliefs are derived from the prior probability distribution using Bayes rule*
$$\omega(\widehat{\theta}) = \frac{\rho}{\rho I_l + (1-\rho)\, I_h}$$
where I_i are index function taking the value 1 whenever the type i is in the set of types that find the signal $\widehat{\theta}$ optimal (choose $\widehat{\theta}$ according to condition 1).

The first conditions states that for any arbitrary belief, both firms maximize their payoffs with respect to the other firms profit maximization. The second condition limits the set of beliefs to those that are reasonable for the strategy profile in question. Another way to put this is to say that the beliefs have to be consistent with the strategy profile if the assessment is to be an equilibrium.[4]

3.2 Pooling equilibrium

As usually in signalling games, we can expect to find both pooling and separating equilibria. Let us start with the first type. The main feature of pooling equilibria is that signals have no real meaning. In other words, the belief function is totally independent from the signals, $\omega(\widehat{\theta}) = \rho$ for any $\widehat{\theta} \in \Theta$. In which case, the conditional expected retail cost of firm 1 is identical to unconditional expected retail cost

$$\begin{aligned} E(c_1|\widehat{\theta}) &= E(c_1) \text{ or} \\ \omega(\widehat{\theta})c_1^h + \left(1 - \omega(\widehat{\theta})\right) c_1^l &= \rho c_1^h + (1-\rho)\, c_1^l. \end{aligned}$$

Another important feature of pooling equilibria in pure strategies is that only when all types send the same signal can the simple prior belief be consistent. With that in mind it is easy to show that a strategy profile where both firms claim to be of type ℓ (low network costs) is not a pooling equilibrium. A firm which has h (high network costs) as its true type, strictly prefers to claim h rather than ℓ if the belief $\omega(\widehat{\theta}) = \rho$ holds. Such a claim has no impact on the payoff from the retail market and only a negative effect on the payoff from the network service for any $\beta > 0$. It would have to accept a lower network tariff while simultaneously running the risk of being punished for a false claim. As the following proposition states there can exist a pooling equilibrium where both types claim to have high network costs, however.

Proposition 1 *Given assumption 3, if the gain in network price when claiming to have high, rather than low, network costs is greater or equal to the expected loss due*

[4]In a more general setting the definition of a PBE requires three additional requirements: 1) that types of different players are uncorrelated, 2) that players cannot make informative signals about other players types, if they do not have more information than the receiver of the signal, and 3) that all players update their posterior beliefs from a common prior in the same way.

These additional requirements are redundent in our game as only one player has private information about his type. For a general definition of PBE in multi-stage games with observed actions and incomplete information we refer to Fudenberg & Tirole (1991, 331-333).

to detection of a false claim,

$$\beta\Delta \geq \varepsilon, \tag{18}$$

there exists a unique pooling perfect Bayesian equilibrium in pure strategies, consisting of the strategy profile $s^p = \left(\phi^p(\theta), \varphi_1^p\left(\theta, \widehat{\theta}\right), \varphi_2^p\left(\widehat{\theta}\right)\right)$, *where*

$$\begin{aligned} \phi^p(\theta) &= h \quad \text{for } \theta \in \{h, l\}, & (19) \\ \varphi_1^p\left(\theta, \widehat{\theta}\right) &= \frac{3c_1^\theta + E(c_1) + 2c_2 + 4\sigma_h}{6} \quad \text{for } \theta \text{ and } \widehat{\theta} \in \{h, l\} \text{ and} & (20) \\ \varphi_2^p\left(\widehat{\theta}\right) &= \frac{E(c_1) + 2c_2 + \sigma_h}{3} \quad \text{for } \widehat{\theta} \in \{h, l\}. & (21) \end{aligned}$$

and the belief $\omega^p\left(\widehat{\theta}\right) = \rho$ *for* $\widehat{\theta} \in \{h, l\}$.

The proof of this and following propositions is given in the appendix. The result illustrates a common concern, that firms may have incentives to overstate their true costs associated with the regulated operation, if they have the opportunity to shift costs from the unregulated operation to the regulated one, with the purpose of receiving a higher compensation for the regulated activity.[5] In the pooling equilibrium the low cost firm gets away with claiming to have high costs in the network operation while neither the regulator nor the entrant can detect its true cost structure. An intuitive criteria for the existence of such an equilibrium is that the gains to a low cost firm claiming to have high costs, $\beta\Delta$, are larger or equal to the expected loss due to successful monitoring of the regulator.

3.3 Separating equilibrium

The incumbent firm has an incentive to overstate its true network costs, as long as the regulated price is responsive to cost claims, i.e., $\beta > 0$. The only counterweight, explicitly mentioned so far, is the expected cost associated with being detected having submitted false cost reports to the regulator. If, however, the rival firm has more sophisticated beliefs a third effect can be added.

As price strategies, in the retail market are compliments, firm 1, who possesses private information, can increase his profit if he convinces firm 2 of that c_1 is high. Such a belief, compared with the prior belief, triggers an increase in p_2, according

[5] Additional motives for shifting costs, beyond the scope of this paper, were mentioned in the introduction.

to the best response function (8), which is met by a smaller increase in p_1. The net effect is a higher price and a larger market share for firm 1. The downside of this, from firm 1's perspective, is that by claiming a high c_1 it simultaneously signals a low c_n, which reduces the revenue from the regulated market.

The following proposition states that, taking these three effects together: a) the network pricing scheme, b) the level of monitoring, and c) the signalling of c_1 to firm 2, there exists a separating equilibrium as long as two incentive compatibility constraints are fulfilled.

Proposition 2 *Given assumption 3, if the incentive compatibility constraints IC_h and IC_l are satisfied, there exists a (information-revealing) separating perfect Bayesian equilibrium in pure strategies consisting of the strategy profile* $s^s = \left(\phi^s(\theta), \varphi_1^s\left(\theta, \widehat{\theta}\right), \varphi^s\left(\widehat{\theta}\right)\right)$ *where*

$$\begin{aligned}
\phi^s(\theta) &= \theta \quad \textit{for } \theta \in \{h, l\}, && (22)\\
\varphi_1^s\left(\theta, \widehat{\theta}\right) &= \frac{2c_1^\theta + c_2 + 2\sigma_h}{3} \quad \textit{for } \theta \textit{ and } \widehat{\theta} \in \{h, l\} \textit{ and} && (23)\\
\varphi_2^s\left(\widehat{\theta}\right) &= \frac{c_1^{\widehat{\theta}} + 2c_2 + \sigma_h}{3} \quad \textit{for } \widehat{\theta} \in \{h, l\}. && (24)
\end{aligned}$$

and the belief $\omega^s(h) = 1$ *and* $\omega^s(l) = 0$.

This result implies that with appropriate selection of parameters controlling incentives through the regulated network price, on the one hand, and monitoring and penalty intensities, on the other, it is possible to resolve the information problem while reducing the average network price, as incumbent firms of type ℓ prefer to reveal their true cost structure.

Two constraints must hold to ensure the existence of a separating equilibrium (see the proof in the appendix for details). The first, is an incentive compatibility constraint on type h,

$$\beta\Delta \geq \frac{2\sigma_h - c_1^h + c_2 + \frac{1}{4}\Delta}{9\sigma_h}\Delta - \varepsilon. \qquad (\mathrm{IC}_h)$$

It states that for type h to prefer to claim its true type rather than pretend to be of type ℓ the difference between the network price each type is permitted to charge (the left hand side) must exceed the increase in profits caused by claiming $\theta = \ell$ net of the expected loss due to successful monitoring.

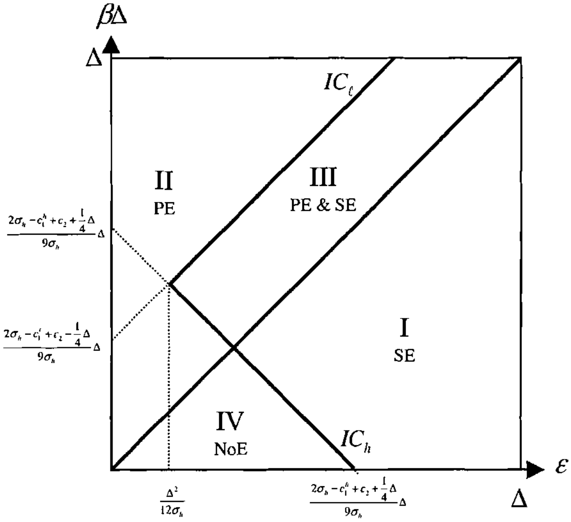

Figure 2: Types of equilibria in the parameterspace $(\beta\Delta, \varepsilon)$

The second, is an incentive compatibility constraint on type l, for it to prefer claiming to be of type l rather than h,

$$\beta\Delta \leq \frac{2\sigma_h - c_1^\ell + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\Delta + \varepsilon. \tag{IC$_l$}$$

For that to hold, the increase in network price when claiming h, rather than l, must be smaller than the lost profit due to the rivals response to the signal in addition to the expected cost from monitoring.

The naive belief, to interpret the signals as the truth, is self-fulfilling as long as these conditions hold. If the regulatory parameters are consistent with them, the incumbent has no incentive to send false signals. If, however, either of these conditions is violated, the respective type has incentives to cheat rendering the naive-belief inconsistent.

The constraints (IC$_h$) and (IC$_l$) together with (18) define four qualitatively different regions in the parameter space $(\beta\Delta, \varepsilon)$ where each type of equilibria can exist or even coexist as shown in Figure 2. The first region, denoted I in the figure, refers to the case when both (IC$_h$) and (IC$_l$) are satisfied while (18) is not. Then a separating equilibrium exists but a pooling equilibrium does not. When either (IC$_h$) or

(IC_l) are not satisfied while (18) still is, only a pooling equilibrium is possible. This is referred to as region II in the figure. Region III shows the case when all three constrains are satisfied at once. Then both separating and pooling equilibria exist. Finally, in region IV where conditions (IC_h) and (18) are violated, no equilibria exist in pure strategies.

The figure also indicates two important properties of the separating equilibrium, more formally put as follows.

Corollary 1 *For a separating equilibrium to exist:*

1. *The expected penalty due to monitoring, ε, must be larger or equal to $\frac{\Delta^2}{12\sigma_h}$.*
2. *As long as $\frac{\Delta^2}{12\sigma_h} \leq \varepsilon < \overline{\varepsilon}$, where*

$$\overline{\varepsilon} = \min\left(\frac{2\sigma_h - c_1^h + c_2 + \frac{1}{4}\Delta}{9\sigma_h}\Delta, \left(1 - \frac{2\sigma_h - c_1^l + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\right)\Delta\right),$$

the power of the pricing scheme, β must be restricted from below and above.

The first restriction, the lower bound on monitoring, is needed for the Spence-Mirrlees condition to hold. If it does not hold while firm 2 has a naive belief, there are three possible outcomes depending on the level of β. For low-powered incentives (small β) , both types would like to claim they have low network costs. For high-powered incentives (large β), both types would like to claim they have high network costs. For intermediate incentives (intermediate β) each type imitates the other types. Only when $\varepsilon \geq \frac{\Delta^2}{12\sigma_h}$ and β is within the bounds indicated in figure 2, can there exist a separating equilibrium where firms make truthful claims about their cost structure and the naive belief is consistent with the firms optimal strategies.

4 Optimal regulation

The obtained results can be summarized as saying that a combination of price incentives and monitoring can incite incumbents to signal their true cost structure. While truth-telling can be obtained with sufficiently intensive monitoring and large fines, irrespective of the network price scheme, a powerful incentive mechanism can partially replace monitoring, while at the same time reduce the informational rent, $\beta\Delta$, diverted to an incumbent with low network costs. A revelation of the incumbents true cost structure reduces the expected regulated network price while at the same time resolves the information asymmetry in the retail duopoly.

4.1 Choosing the "best" separating equilibrium

Assuming that a truth-revealing separating equilibrium is desirable, we would like to say something about the optimal choice of incentive and monitoring parameters. In order to do that we need to specify a reasonable objective function for the regulator. As demand is completely inelastic, changes in prices are pure transfers between firms and consumers, and should not concern the regulator if he has balanced preferences for the welfare of consumers and firms. Still, relatively higher emphasis on consumer surplus is justifiable for two reasons. First, the model is too simple in this respect and in a more realistic model a price increase would impede total welfare. Second, a certain price level can be viewed by consumers as focal, so that a deviation from that price level calls for compensation - be that through taxes cuts, increased subsidies or in some other latent form. Any such compensating transfers would require alternative financing. Hence, it is reasonable to consider the cost of public funds required for such transfers. We assume, for simplicity, that the expected price level enters regulator's objective function weighted against the cost of monitoring. The weight used can then be interpreted in a number of ways, e.g., a function of the ratio of the deadweight loss to a price change or the cost of public funds. The retail price level is independent of the regulatory parameters, in a separating equilibrium. The expected network price, on the other hand, is directly controlled by the variables α and β :

$$E(p_n) = \alpha - (1-\rho)\beta\Delta.$$

Recall that ρ is the probability of the incumbent firm being of type h. The expected network price is increasing in α but decreasing in β.

The regulator is also concerned with the costs associated with monitoring. To save on notation we use the expected loss of detection, ε, from the incumbents perspective, as the choice variable rather than the monitoring intensity, m, and the fine, f. The regulator always prefers to set the level of the fine to its maximum, as in Baron & Besanko (1984). This is fairly natural since the fine can be considered a pure transfer, while monitoring is a real cost. The expected cost equals the probability of detection $\gamma(m, \Delta)$, a function of monitoring intensity and the difference between the types' costs, times the fine, f. Monitoring pressure is produced with a decreasing returns to scale technology. Let $d(\varepsilon)$ be a twice differentiable cost function with $d' > 0$ and $d'' > 0$.

The regulators objective is to minimize the weighted sum of the expected network price and the cost of monitoring, O_R,

$$O_R = \alpha - (1-\rho)\,\beta\Delta + \mu d(\varepsilon)\,, \tag{25}$$

μ being a scale parameter, the inverse of the weight put on prices. The regulator has three parameters to set α, β and ε. We have already discussed the incentive compatibility constraints but in addition we must consider the respective individual rationality (IR) constraints. We choose to assume that each type of incumbent firm is assured a nonnegative profit from the network operation. This is by no means the only plausible reference point. A somewhat less restrictive constraint would be to require combined profits of the incumbent to positive (see e.g. Sappington (2003)). Given the significant market power an incumbent has in the retail market, this can result in a pure loss from the network operation for high cost firm. It could prove difficult to require a firm to fulfill a service at a loss, even if it is regarded as an essential facility. The loss of political reputation resulting in disruption of electric services, for example, gives an incumbent firm a serious potential threat in a such a situation. Hence, the IR constraints used here are

$$\alpha - c_n^h \geq 0 \tag{IR$_h$}$$

$$\alpha - \beta\Delta - c_n^l \geq 0. \tag{IR$_l$}$$

Proposition 3 *Assuming that a separating equilibrium is preferred to pooling equilibrium, the regulator's optimal policy, minimizing (25) with respect to (IC$_h$), (IC$_l$),(IR$_h$) and (IR$_l$), is to set α, β and ε such that*

$$\begin{aligned} \alpha &= c_n^h, && (26)\\ \varepsilon &= \min\left(\Delta, \max\left(\frac{\Delta^2}{12\sigma_h}, \varepsilon^*\right)\right) \quad \textit{and} && (27)\\ \beta\Delta &= \frac{2\sigma_h - c_1^\ell + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\Delta + \varepsilon. && (28) \end{aligned}$$

where $\varepsilon^*$is a potential interior solution of ε defined by $d'(\varepsilon^*) = \frac{1-\rho}{\mu}$.

The intuition is best explained with the aid of figure 3. The unconstrained

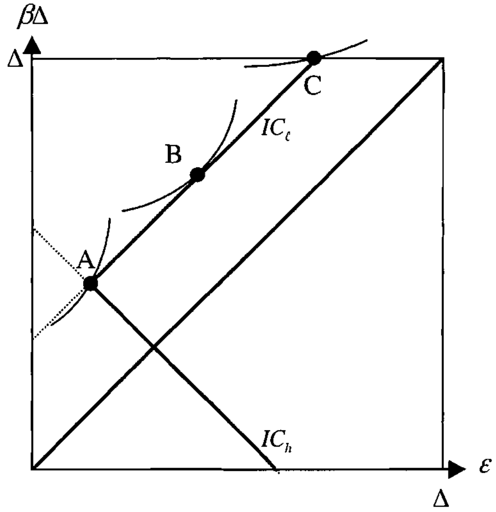

Figure 3: Three types of optimal regulation

minimization of O_R would yield the solution $\beta = 1$, $\varepsilon = 0$, where neither type of incumbent were left with any informational rent and costly monitoring could be avoided. In general a move in the depicted parameter space to the northwest is an improvement for the regulator's objective. The slope of the indifference curves depends on the monitoring cost function d. In any case the incentive compatibility constraint for the low network cost firm (IC_l) is binding, as it defines an upper bound on β which is increasing in ε. Depending on the slope of the indifference curves, three qualitatively different solutions may emerge.

If the marginal cost of monitoring increases very fast with monitoring intensity the slope of the indifference curve is so steep, that the incentive compatibility constraint for the high cost firm also kicks in (IC_h) and we have a corner solution at point A. The high level of monitoring cost (at the margin at least) makes it attractive to reduce monitoring at the expense of more informational rents to a firm claiming to have low network costs. But lowering the monitoring intensity below the critical level, $\frac{\Delta^2}{12\sigma_h}$, makes it attractive for the high cost firms, to falsely claim to have low costs. Even though such a claim would result in lower network price, it would be more then compensated by the increase in retail price if the rival firm would believe the incumbent really had low network costs implying high retail costs.

For an intermediary increase in the marginal costs when the intensity of monitoring increases, a solution like the one indicated by point B in the figure is made possible, where the balance is struck between monitoring and the incentive scheme. Assume for instance that the cost of monitoring is given by $d(\varepsilon) = \frac{\delta}{2}\varepsilon^2$. Then the marginal cost of monitoring is $d'(\varepsilon) = \delta\varepsilon$. Since the interior solution ε^* is defined by $d'(\varepsilon^*) = \frac{1-\rho}{\mu}$ we would have $\varepsilon^* = \frac{1-\rho}{\mu\delta}$.

If the marginal cost of monitoring increases very slowly with monitoring intensity the indifference curve is relatively flat and is not tangent to (IC_l) within the feasible parameter space. In that case the regulator does not leave any informational rent to the high cost firm and relies on extensive monitoring to make it worthwhile for the high cost firm to give a truthful signal about its cost structure. This situation is indicated by point C in the figure.

4.2 Choice of equilibrium and welfare implications

So far we have seen that it is possible for the regulator to induce a truth-telling separating equilibrium. We have also characterized the optimal choice of β and ε given that the separating equilibrium is preferable to the pooling equilibrium. It is, however, not clear if the regulator should choose to implement separating equilibrium instead of pooling equilibrium. If the regulator seeks to maximize the expected consumer surplus net of switching costs and monitoring cost, the choice of equilibrium depends on a combination factors.

In a pooling equilibrium, the choice of β is irrelevant, as both types claim to be of type h. Hence, consumers pay a lower expected network price in the separating equilibrium when a positive β reduces the network price in case the incumbent is of type ℓ. The expected difference been the network price in the two cases is

$$E(p_n^p) - E(p_n^s) = (1-\rho)\beta\Delta > 0. \tag{29}$$

Moving from one type of equilibrium to another has more profound effects in the retail market. If firm 1 has low production costs in the retail market, i.e., is of type h, firm 2 would decrease its price in the separating equilibrium compared with the pooling equilibrium. Firm 1 would respond with a smaller price reduction, and as a consequence firm 2's market share would be larger in the separating equilibrium compared with the pooling equilibrium. On the other hand, if firm 1 is of type ℓ and has high production costs in the retail market, firm 2 would increase its price in the separating equilibrium and firm 1 would respond with a smaller increase. Hence, firm 2's market share would be smaller in a separating equilibrium than in a pooling equilibrium.

The equilibrium retail price in the pooling equilibrium and the separating equilibrium are given by propositions 1 and 2 respectively, and the equilibrium quantities in are derived from (11) and (12). It is easy to verify that the expected price and expected quantities are identical in each type of equilibria. Expected total expenditure (excluding the network price) is not, however.

Let $e_r(p_1, p_2, q_1, q_2)$ denote the aggregate expenditure electricity, excluding the network price. The expected expenditure in each type of equilibria is then,

$$\begin{aligned} E(e_r^p) &= \rho\left(p_1^p(h)\, q_1^p(h) + p_2^p q_2^p(h)\right) + (1-\rho)\left(p_1^p(\ell)\, q_1^p(\ell) + p_2^p q_2^p(\ell)\right) \\ E(e_r^s) &= \rho\left(p_1^s(h)\, q_1^s(h) + p_2^s(h)\, q_2^s(h)\right) + (1-\rho)\left(p_1^s(\ell)\, q_1^s(\ell) + p_2^s(\ell)\, q_2^s(\ell)\right). \end{aligned}$$

The convention used in super- and subscripts is the same as used before. Equilibrium prices and quantities are functions of the incumbent's type, except the price of the entrant in pooling equilibria, p_2^p, when the signal is uninformative. Using the equilibrium prices and quantities derived above, we find the difference in expected aggregate expenditure between the pooling and separating equilibria to be

$$E(e_r^p) - E(e_r^s) = -\frac{5}{36}\frac{\rho(1-\rho)\Delta^2}{\sigma_h} < 0. \tag{30}$$

The expected total consumer expenditure is higher in the separating equilibrium compared with the pooling equilibrium.

As market shares can be different between different types of equilibria, switching costs incurred by consumers can also vary. Recall that marginal consumer's switching cost is given by

$$\tilde{\sigma} = p_1 - p_2$$

and all consumers with $\sigma \leq \tilde{\sigma}$ will switch. Firm 2's market share as a function of prices is $q_2 = \frac{p_1 - p_2}{\sigma_h}$ and, due to the simple uniform distribution of switching cost, the total switching cost incurred by the consumers is

$$\Sigma = \int_0^{p_1 - p_2} \sigma \frac{1}{\sigma_h} d\sigma = \frac{(p_1 - p_2)^2}{2\sigma_h}.$$

The difference in expected total switching costs between the pooling and separating equilibria is then given by

$$E(\Sigma^p - E(\Sigma^s) = \frac{5}{72}\frac{\rho\,(1-\rho)\,\Delta^2}{\sigma_h} > 0, \tag{31}$$

where Σ^p and Σ^s are aggregate switching costs evaluated at pooling equilibrium and separating equilibrium prices respectively. Evidently, the total expected switching cost incurred by consumers is larger in the pooling equilibrium.

With reference to (1) and (2), we can express aggregate consumer surplus as the intrinsic value of the service, s, subtracted by the p_n, e_r and Σ:

$$U = s - p_n - e_r - \Sigma.$$

The change in expected consumer surplus going from a pooling to the separating equilibrium is then

$$E(U^s) - E(U^p) = (1-\rho)\Delta\left(\beta - \frac{5}{72}\frac{\rho\Delta}{\sigma_h}\right). \tag{32}$$

We can now state the following result.

Proposition 4 *Given assumption 3, expected consumer surplus is larger in a separating equilibrium than in a pooling equilibrium.*

While consumers, on the whole, are always better off in a separating equilibrium than a pooling equilibrium, as long as both firms are active in the market (assumption 3) the regulator should weigh consumer gains against the cost of monitoring, which is required to uphold a separating equilibrium. A regulator might also be concerned with firms' profits, at least to the extent they reflect market efficiency. Firm 2's market share is smaller when the retail cost of firm 1 is relatively high (and larger when c_1 is low) in a separating equilibrium relative to a pooling equilibrium. This means that production will be less efficient in a separating equilibrium than in a pooling equilibrium. But due to the simple modelling framework we prefer leave the formal analysis of this issue for future work.

5 Conclusion

An incumbent firm is not only interested in convincing the regulator that it has high costs in its network business. It would also like its rival to believe that retail costs are high. This constitutes a trade-off if firms compete by setting prices, which are strategic compliments. If an incumbent manages to convince its competitor that its retail costs are high, it can expect the rival firm to set a higher price than otherwise. If firms compete in quantities, à la Cournot, where strategies are substitutes, trade-off would not exist and an incumbent firm would always prefer to look as if it had high network costs and low retail cost. Consequently, the incumbent's true cost structure could not be identified through a signalling process as described above. The same is true if the rival is non-strategic, e.g., represents a competitive fringe. Then the incumbent has no interest in trying to affect its rival's belief, since its price setting behavior would be unaffected by any attempts to signal high retail costs.

There is little doubt in our minds, that retail competition in electricity market is better characterized with prices than with quantities as the primary strategic variable. Individual retailers are seldom capacity constrained, as they can always buy additional power on the wholesale market. The two firm model is admittedly a simplification of real-world markets. Similar results, though perhaps not as strong, are likely to emerge in a model with a more realistic market structure, as in (Green 2000).

In this paper we have shown that a regulator can induce a truth-revealing separating equilibrium by a combination of pricing incentives and monitoring. Strategic interaction in the retail market allows the regulator to achieve this at a lower monitoring cost than otherwise would be possible. Consumers gain from such a policy through a lower network price, but the benefit is partially offset by a increased retail expenditures. The separating equilibrium can also lead to a loss in efficiency as an entrant increases its market share if the incumbent has relatively low retail costs and decreases its market share when the incumbent has relatively high retail costs in a separating equilibrium compared with a pooling equilibrium. More importantly though, the problem of cost-shifting by a regulated firm can be reduced or alleviated, if the firm in question is a strategic player in an (imperfectly competitive) unregulated market.

Appendix

Proof of proposition 1.

Consider the belief $\omega^p\left(\widehat{\theta}\right)=\rho$ for $\widehat{\theta}\in\{h,l\}$. Strategy profiles where $\phi(h)\neq\phi(l)$ can be excluded as they are inconsistent with the belief and by condition 2 (definition 1) can not be a part of a PBE. Any strategy profile in which $\phi(h)=l$, given $\omega^p\left(\widehat{\theta}\right)$, can not belong to an equilibrium either. Clearly by (16) $\phi(h)=l$ is strictly dominated by $\phi(h)=h$.

What we are left with are strategy profiles where $\phi(\theta)=h$ for $\theta\in\{h,l\}$. Price enters the objective function of firm 1, (16) only in the last term, which is independent of $\widehat{\theta}$. Hence, the choice of ϕ and φ are independent decisions. Under assumption 3 there are unique best response functions for the firm's price strategies

$$\begin{aligned} b_1(p_2|\theta) &= \frac{c_1^\theta+p_2+\sigma_h}{2}, \\ b_2(p_1) &= \frac{c_2+E(p_1)}{2}. \end{aligned}$$

Solving these together returns (20) and (21).

The assessment (s^p,ω^p) can only be a pooling equilibrium if both types have incentives to claim to be of type h. That is, if $\pi_1(\varphi_1^p(\theta,h),h|\theta)\geq\pi_1(\varphi_1^p(\theta,l),l|\theta)$ for $\theta\in\{h,l\}$. We have already seen that $\varphi_1^p(\theta,h)=\varphi_1^p(\theta,l)$ and hence from (16) we have

$$\begin{aligned} \pi_1(\varphi_1^p(h,h),h|h)-\pi_1(\varphi_1^p(h,l),l|h) &= \beta\Delta+\varepsilon \text{ and} \\ \pi_1(\varphi_1^p(l,h),h|\ell)-\pi_1(\varphi_1^p(l,l),l|l) &= \beta\Delta-\varepsilon. \end{aligned}$$

Thus, a firm of type h will always find it optimal to claim h for any values of the parameters β,Δ and ε, while a firm of type ℓ only finds sending the signal h optimal if $\beta\Delta\geq\varepsilon$. If $\beta\Delta<\varepsilon$ firm of type l could increase its payoff by claiming l while a firm of type h chooses to claim h. But then the belief $\omega\left(\widehat{\theta}\right)=\rho$ is not consistent. ■

Proof of proposition 2.

Take the belief where $\omega^s(h)=1$ and $\omega^s(l)=0$ as given. Then, firm 2 perceives firm 1's best response function to be $b_1(p_2)=\frac{p_2+c_1^{\widehat{\theta}}+\sigma_h}{2}$. Maximizing (17) with respect to p_2 yields a unique optimal strategy for firm 2 as a function of the signal sent by firm 1: $\varphi_2^s\left(\widehat{\theta}\right) = \frac{c_1^{\widehat{\theta}}+2c_2+\sigma_h}{3}$. In order order to fulfill condition (2) of definition 1 (consistency of strategies and beliefs) two incentive compatibility constraints must hold, one for each type.

Type h. Firm 1's objective function, given firm 2's optimal strategy is

$$\pi_1\left(p_1,\widehat{\theta}|\theta\right) = \alpha - \beta(c_n^h - c_n^{\widehat{\theta}}) - c_n^\theta + \left(p_1 - c_1^\theta\right)\frac{\sigma_h + \frac{2c_2+c_1^{\widehat{\theta}}+\sigma_h}{3} - p_1}{\sigma_h}. \tag{33}$$

Consider a firm 1 of type h. If it claims $\widehat{\theta} = h$, (33) is maximized by selecting

$$p_1 = \varphi_1^*(h,h) = \frac{2\sigma_h + 2c_1^h + c_2}{3} \tag{34}$$

yielding the profit

$$\pi_1^*(h,h) = \alpha - c_n^h + \frac{\left(2\sigma_h - c_1^h + c_2\right)^2}{9\sigma_h},$$

where $\pi_1^*\left(\theta,\widehat{\theta}\right) = \pi_1\left(\varphi_1^*\left(\theta,\widehat{\theta}\right),\widehat{\theta}|\theta\right)$ is the reduced form profit function of type θ that claims $\widehat{\theta}$. A firm of type h who sends the signal ℓ, maximizes (33) by selecting $p_1 = \varphi_1^*(h,\ell) = \frac{2\sigma_h+\frac{3}{2}c_1^h+\frac{1}{2}c_1^\ell+c_2}{3}$ yielding the profit

$$\pi_1^*(h,\ell) = \alpha - \beta\Delta - c_n^h - \varepsilon + \frac{\left(2\sigma_h - c_1^h + c_2 + \frac{1}{2}\Delta\right)^2}{9\sigma_h}.$$

A firm of type h prefers to send the true signal h and select the retail price, $\varphi_1^*(h,h)$ only if $\pi_1^*(h,h) \geq \pi_1^*(h,l)$. This gives the following incentive compatibility constraint for type h

$$\beta\Delta \geq \frac{2\sigma_h - c_1^h + c_2 + \frac{1}{4}\Delta}{9\sigma_h}\Delta - \varepsilon. \tag{35}$$

If (35) does not hold an incumbent of type h will prefer to claim $\widehat{\theta} = l$ rendering the belief inconsistent.

Type l. Then consider an incumbent firm of type l. If it claims $\widehat{\theta} = l$, (33) is maximized by selecting

$$p_1 = \varphi_1^*(\ell,\ell) = \frac{2\sigma_h + 2c_1^l + c_2}{3} \tag{36}$$

yielding the profit

$$\pi_1^*(\ell,\ell) = \alpha - \beta\Delta - c_n^\ell + \frac{\left(2\sigma_h - c_1^l + c_2\right)^2}{9\sigma_h}.$$

A firm of type l who sends the signal h, maximizes profit by selecting $p_1 = \varphi_1^*(l,h) = \frac{2\sigma_h + \frac{1}{2}c_1^h + \frac{3}{2}c_1^\ell + c_2}{3}$ yielding the profit

$$\pi_1^*(\ell,h) = \alpha - c_n^\ell - \varepsilon + \frac{\left(2\sigma_h - c_1^l + c_2 - \frac{1}{2}\Delta\right)^2}{9\sigma_h}.$$

A firm of type l prefers to send the true signal l and select the appropriate price, $\varphi_1^*(,l)$ only if $\pi_1^*(l,l) \geq \pi_1^*(\ell,h)$. This gives the following incentive compatibility constraint for type l

$$\beta\Delta \leq \frac{2\sigma_h - c_1^l + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\Delta + \varepsilon. \tag{37}$$

If $\pi_1^*(l,l) < \pi_1^*(l,h)$ a firm of type l will prefer to claim $\widehat{\theta} = h$ and the belief is inconsistent.

When both (35) and (37) hold, the price strategies (34) and (36), which fulfill condition (1), make it optimal for either type to signal its true cost structure. If either (35) or (37) fails to hold the respective type will prefer to make a false claim about its true type. ■

Proof of correlary 1.

Part 1. The two constraints (IC_h) and (IC_l) put together give

$$\frac{2\sigma_h - c_1^l + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\Delta + \varepsilon \geq \beta\Delta \geq \frac{2\sigma_h - c_1^h + c_2 + \frac{1}{4}\Delta}{9\sigma_h}\Delta - \varepsilon.$$

Using $c_1^\ell - c_1^h = \Delta$, the two inequalities turn into equalities if $\varepsilon = \frac{\Delta^2}{12\sigma_h}$. Clearly when $\varepsilon < \frac{\Delta^2}{12\sigma_h}$ the inequalities are violated, while for any $\varepsilon \geq \frac{\Delta^2}{12\sigma_h}$ they hold, due to the positive sign on ε on the left of the first inequality and negative sign after the second inequality.

Part 2. For a fixed Δ and ε condition (IC_h) defines a lower bound on β that are consistent with a separating equilibrium. It is strictly larger than zero when $\varepsilon < \frac{2\sigma_h - c_1^h + c_2 + \frac{1}{4}\Delta}{9\sigma_h}\Delta$ (as shown in figure 2). Condition (IC_l) defines an upper bound on β that are consistent with a separating equilibrium. The upper bound is strictly smaller then 1 when $\varepsilon < \left(1 - \frac{2\sigma_h - c_1^\ell + c_2 - \frac{1}{4}\Delta}{9\sigma_h}\right)\Delta$. ■

Proof of proposition 3.

1. To minimize (25) with respect to α, either (IR$_h$) or (IR$_l$) will be binding. If $\beta \geq 1$, then the optimal α is $\alpha > c_n^h$, as required for (IR$_l$) to hold. But since $\rho > 0$, the objective can be improved by decreasing α and $\beta\Delta$ by the same amount. When $\beta < 1$ (IR$_l$) is never binding, since $\alpha - \beta\Delta - c_n^\ell = \alpha - \beta\left(c_n^h - c_n^l\right) - c_n^l > \alpha - c_n^h$. Hence, (IR$_h$) is binding and $\alpha = c_n^h$.

2. Given $\alpha = c_n^h$ it is convenient to proceed with reference to figure 3. The objective function (that is minimized) is strictly decreasing in β (a larger β is an improvement). As (IC$_h$) only defined a lower bound on β it is never a binding constraint, unless (IC$_l$) is also binding, as is the case indicated by point A in figure 3. Also, because the objective is strictly decreasing in β, the (IC$_l$), which defines an upper bound to β is always binding.

3. Hence, the optimal β and ε are found on a line determined by the binding (IC$_l$) constraint. The β and ε are further constrained from below by (IC$_h$), implying
$$\beta \geq \tfrac{2\sigma_h - \frac{1}{2}\left(c_1^l + c_1^h\right) + c_2}{9\sigma_h} \quad \text{and} \quad \varepsilon \geq \tfrac{\Delta^2}{12\sigma_h}$$
when both (IC$_h$) and (IC$_l$) hold simultaneously (see point A in figure 3, and above by the result from step 1 that $\beta \leq 1$, implying $\varepsilon \leq \Delta\left(1 - \frac{2\sigma_h - \frac{1}{2}\left(c_1^l + c_1^h\right) + c_2 - \frac{3}{4}\Delta}{9\sigma_h}\right)$ (point B in figure 3). These bounds are indicated in figure 3 by A and B respectively as well as examples of indifference curves that could facilitate corner solutions. Point C is an example of a solution which is only constrained by (IC$_l$).

4. The potential interior solution ε^* is found by taking the first order condition *w.r.t.* β
$$(1 - \rho) = \lambda$$
and the first order condition *w.r.t.* ε
$$\mu d'(\varepsilon) = \lambda$$
and we see that
$$d'(\varepsilon) = \frac{(1 - \rho)}{\mu}.$$

■

Proof of proposition 4.

Inserting the optimal β given by proposition 3 in equation (32) yields

$$\frac{(1-\rho)\Delta}{72\sigma_h}\left(8c_2 - 2\Delta + 16\sigma_h - 8c_1^l - 5\rho\Delta + \frac{72\sigma_h\varepsilon}{\Delta}\right). \tag{38}$$

If the consumers are to gain from a separating equilibrium compared with a pooling equilibrium this expression must be strictly positive. Since the factor outside the parenthesis is clearly positive this translates into a condition requiring that the part within the parenthesis is positive. This expression is increasing in c_2 as well as ε. The lower bound on c_2 is given by assumption 3 and according to proposition 2 the monitoring intensity must exceed a lower bound, $\varepsilon \geq \frac{\Delta^2}{12\sigma_h}$, for a separating equilibrium to exist. Inserting these into equation (38) and simplifying somewhat the expression within the parenthesis is reduced to $\Delta(4-\rho) > 0$ since $\rho < 1$. Equation (38) is positive for the lowest possible c_2 and the lowest possible ε and it must then also be positive for any higher c_2 and ε. ■

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Chapter 4

Does Your Opponent's Experience Matter? Experimental Evidence From a Quantity Precommitment Game

Does Your Opponent's Experience Matter? Experimental Evidence from a Quantity Precommitment Game*

Chloé Le Coq Jon Thor Sturluson

Abstract

This paper investigates why subjects in laboratory experiments on capacity constrained price competition seem to consistently choose capacity above the Cournot level - the subgame-perfect equilibrium. We argue that this puzzling regularity may be attributed to players' perceptions about their opponents skill or level of rationality. In our experimental design we used the level of experience (number of periods played) as a proxy for the level of rationality and matched subjects with different levels of experience. We found evidence of capacity choices being decreasing and prices increasing with opponent's experience. This suggests that if subjects have a tendency to underestimate the rationality of their opponents, or that rationality is actually limited for a large proportion of subjects, the observed regularity need not be a puzzle after all.

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1 Introduction

One of the most prominent solutions to the Bertrand paradox is to take capacity constraints into consideration when looking at price competition. Kreps & Scheinkman (1983), henceforth KS, consider a game where firms commit simultaneously to a capacity level before they compete in prices, à la Bertrand. Their seminal result was that the unique subgame-perfect equilibrium implies capacities equal to the Cournot Nash equilibrium.

A puzzling empirical regularity has been identified in several experiment studies focusing on the KS model. A large majority of subjects consistently choose capacities above the Cournot equilibrium level. This has been the case even if the experiments were designed to respect all the assumptions[1] under which the Cournot outcome is the unique subgame-perfect equilibrium. In the first paper that specifically tests the KS result, Davis (1999) examines the effect of capacity investments (or its equivalent production to stock) on the outcome of a posted-offer market. According to his results, capacity precommitment has significant positive effects on prices and negative effects on output. However, the increase in prices and reduction in output is much smaller than predicted by the KS model. Outcomes are volatile and generally fail to converge to the subgame-perfect equilibrium (the Cournot outcome), and excess capacity prevails throughout the sessions. In an independent but similar paper, Muren (2000) reports on two experimental treatments; one with experienced and the other with inexperienced players, in a pure KS game. Deviations from the Cournot outcome, in the form of larger capacities and lower prices than those predicted by KS, decrease with experience but do not disappear. She argues that excess capacity could result from subjects not fully understanding the mechanism of the game, in particular the efficient rationing rule which creates a discontinuity in payoffs. Anderhub et al. (2002) took a closer look at Muren's argument. Their experimental environment differed from the previous studies in that they set up a heterogenous-goods duopoly with 'soft' capacity constraints. The capacity choice is still important because all production in excess of the target capacity level is penalized by an extra cost which is chosen to be higher than the equilibrium price. Furthermore, they repeat the price subgame for 10 periods after each quantity choice

[1] Some important assumptions made by Kreps and Scheinkman have been criticized for being too restrictive, e.g., concave demand, efficient rationing and perfect information (see for example Davidson and Deneckere, 1986 or Reynolds and Wilson, 2000).

stage. Both these features are intended to make it easier for subjects to find the subgame equilibrium in prices. Even though price choices are, in general, consistent with the subgame perfect prediction, the selected capacities are more often than not above the Cournot prediction. This suggests that failure to understand the structure of the game is not a principal explanation of the mentioned regularity.

Understanding the implications of capacity chosen in the first stage for optimal price choice in the second stage, as induced in Anderhub et al. (2002), is one thing. To grasp the full consequences of ones own capacity choice on future price choices, particularly by others, is quite another. Moreover, if players (being fully rational themselves) expect their opponents not to be fully rational - that they may deviate from optimal strategies at times - the Cournot equilibrium might not be the best prediction of a rational player's capacity choice. In fact, we show that if a player thinks his opponent can make mistakes, e.g., by offering a price higher than the market clearing price, he will find it optimal to choose a capacity above the Cournot level.

This paper reports on an experiment that was designed to test if players' perceptions about their opponents skills, or level of rationality, affects behavior systematically. By level of rationality we mean the degree of precision with which a player observes his payoff and refer to less than perfect precision as bounded rationality, in the spirit of McKelvey & Palfrey (1995) and Sargent (1994). While unable to control for players' level of rationality directly, we can use their level of experience in playing the game as a reasonable proxy.[2] By matching subjects with different levels of experience (both being aware of each others experience level), we can test our main hypothesis, namely, that beliefs about opponents' rationality matter and that pessimistic beliefs can be an important cause of observed overcapacity in KS games.

In all previous KS experiments, subjects have played in fixed pairs or groups throughout their sessions. Hence, large capacities may be caused by individual attempts to become dominant producers. If a player succeeds in convincing his opponents that he will choose a high capacity regardless of what the others do, their best response is to reduce their capacity as if the first player were a Stackelberg leader who had committed to a high capacity level. Here we choose to match subjects randomly in order to eliminate any such motives. One session was run with fixed

[2]The implicit assumption is that experienced players can be expected to play more rationally (makes fewer mistakes) than inexperienced ones.

pairs, in part to check if our experimental design would yield results consistent with previous experiments.

The remainder of this paper is structured as follows. The next section provides a general description of the experimental design and procedures. Using a simple example, we illustrate how a fully rational player can be expected to choose capacity above the Cournot level if he expects his opponent to be irrational. Section 3 presents the results of the experiment which support our main hypothesis that an opponent's experience level significantly affects behavior. Capacities are larger and prices lower, on average, when opponents are inexperienced, compared with when opponents are experienced. Comparison of treatments with similarly experienced subjects and different matching rules, does not support the hypothesis that a strategic motive is the cause of overcapacity. We investigate the observed behavioral patterns further in section 4. The predictions provided in section 2 are generalized using the agent-form quantal response equilibrium model (McKelvey & Palfrey 1998). Section 5 concludes, discussing some important implications of the results and suggestions for further research.

2 Experimental Design

2.1 General description

We start off by briefly presenting the simple Kreps-Scheinkman (KS) model used in the experiment and the standard game-theoretic prediction of behavior. Then we go on to illustrate, using a simple example, that when a rational player expects his opponent to play irrationally he chooses a capacity level that is greater than the Cournot output level as well as a price that is below the Cournot price level.

2.1.1 The benchmark model

Consider a simple version of Kreps' and Scheinkman's (1983) symmetric duopoly model with a homogenous product, constant marginal cost and linear demand, played by perfectly rational players. The game consists of two stages. In the first stage, players choose their capacity level q_1 and $q_2 \in \mathbb{R}_+$ simultaneously. At the second stage, having learned the capacity choices made by their opponent, they choose prices simultaneously, p_1 and $p_2 \in \mathbb{R}_+$. Adopting the efficient rationing rule, player

i's payoff is given by:[3]

$$\pi_i(q_i, q_j, p_i, p_j) = \begin{cases} p_i \min(q_i, d(p_i)) - cq_i & \text{if } p_i < p_j, \\ p_i \min(q_i, \max(d(p_i) - q_j, d(p_i)/2)) - cq_i & \text{if } p_i = p_j, \\ p_i \min(q_i, \max(d(p_i) - q_j, 0)) - cq_i & \text{if } p_i > p_j. \end{cases} \tag{1}$$

where $i, j \in \{1, 2\}$ and $i \neq j$, and $d(p_i) = \alpha - \beta p_i$. In our experimental setup we chose the parameters $\alpha = 120$, $\beta = 1$ and $c = 30$ which are, in relative terms, similar to those used by Muren (1999). With these parameters, the Cournot equilibrium is stable and significantly different from the competitive solution. It is also easy to verify that the subgame-perfect equilibrium is unique and equal to the Cournot outcome in terms of capacities, prices and profits:[4]

$$q_i^c = 30,\ p_i^c = 60 \text{ and } \pi_i^c = 900 \quad \text{for } i \in \{1, 2\}. \tag{2}$$

In comparison, a competitive market would yield aggregate output equal to 90, prices equal to marginal cost, 30, and zero profits.

2.1.2 A simple example with one irrational player

Now, consider a variation of the benchmark model where players can only choose among three capacity levels $\{20, 30, 40\}$ and three price levels $\{55, 60, 65\}$. Notice that the feasible choices are symmetric around the Cournot outcome. Player 1 is perfectly rational as before. He chooses a strategy that maximizes his expected payoff given a consistent belief about player 2's strategy. The main change from the benchmark case is that player 2 is irrational. More specifically, he chooses strategies at random.

Let us consider player 1's optimal strategy. If player 1 chooses the Cournot

[3] The payoff function was not described to the subjects in algebraic form, but using words. See the complete instructions in the appendix.

[4] Follows straight from proposition 2 in Kreps and Scheinkman (1983).

output, 30, his optimal price strategy[5] is

$$p_1^*\left(q_1 = 30, q_2 = \begin{bmatrix} 20 \\ 30 \\ 40 \end{bmatrix}\right) = \begin{bmatrix} 65 \\ 60 \\ 55 \end{bmatrix}. \tag{3}$$

and because player 2 chooses each available price level with probability $\frac{1}{3}$, player 1's expected profit is

$$E(\pi_1 | q_1 = 30) = \frac{1}{3} \times 65 \times 30 + \frac{1}{3} \times 60 \times 30 + \frac{1}{3} \times 55 \times 30 - 30 \times 30 = 900.$$

Notice that he manages to sell all of his capacity whatever player 2 does. If, however, player 1 chooses $q_1 = 40$, his optimal price strategy, depending on q_2 is

$$p_1^*\left(q_1 = 40, q_2 = \begin{bmatrix} 20 \\ 30 \\ 40 \end{bmatrix}\right) = \begin{bmatrix} 60 \\ 55 \\ 55 \end{bmatrix} \tag{4}$$

and his expected profit is

$$E(\pi_1 | q_1 = 40) = \frac{1}{3} \times 60 \times 40 + \frac{2}{3} \times 55 \times \left(\frac{2}{3} \times 40 + \frac{1}{3} \times \frac{65}{2}\right) - 30 \times 40 = 975.$$

Going from left to right, the right hand side is obtained as follows. Player 2 chooses $q_2 = 20$ with probability $\frac{1}{3}$, in which case player 1's revenue is 60×40. But if player 2 chooses $q_2 = 30$ or 40, player 1 should react by choosing a low price, $p_1 = 55$ by (3). Then he is able to sell to capacity as long as player 2 chooses a higher price (with probability $\frac{2}{3}$) and receive 55×40 in revenue. However, with probability $\frac{1}{3}$ player 2 will match firm 1's low price and demand is split equally between the two players resulting in the revenue $\frac{65}{2} \times 40$ for player 1. Cost is independent of actual sales and is always $30 \times 40 = 1200$. The expected profit is 975 compared with 900 when the capacity is equal to the Cournot output. Hence, choosing a capacity level

[5] The optimal price strategy (3) comes straight from (1). Take for instance the case when $(q_1, q_2) = (30, 30)$. If player 1 selects $p_1 = 65$ he will not be able to sell to full capacity. With probability $\frac{2}{3}$, when $p_2 = 55$ or 50, player 1 can only sell the residual demand $120 - 30 - 65 = 25$ and with probability $\frac{1}{3}$, $p_2 = 65$ the aggregate demand is split leaving $\frac{55}{2}$ for player 1. His expected revenue is then $65 \times \left(\frac{2}{3} \times 25 + \frac{1}{3} \times \frac{55}{2}\right) = 1679.2$. If he chooses $p_1 = 60$, he will be able to sell all his capacity, no matter what p_2 is, giving him the expected revenue $60 \times 30 = 1800$. Clearly $p_1 = 55$ is inferior as sales are already at the capacity level at $p_1 = 60$.

considerably greater than the Cournot output is optimal under these circumstances.

This example is very specific. One player is perfectly rational - observes his payoff with certainty and has correct beliefs about the other player's strategy - and one player is completely irrational - choosing strategies at random. On top of that, the action space is quite restrictive. Still, it serves to illustrate that players' perceptions about their opponents skill or level of rationality influence the outcome of the game. Furthermore, it can be generalized for any level of skill, using the agent-form quantal response equilibrium (McKelvey & Palfrey 1998), where the level of rationality is defined as the accuracy with which players observe their true payoff function. We discuss this theoretical setup in section 4. It turns out that overcapacity is predicted for any combinations of players with different levels of rationality.

Let's make it clear that by level of rationality we mean the degree of precision with which a player observes his payoff, and refer to less than perfect precision as bounded rationality, as do McKelvey & Palfrey (1995) and Sargent (1994). While we are unable to control for players' level of rationality, we can use their level of experience in playing the game as a reasonable proxy. We explicitly matched subjects with different levels of experience to test our main hypothesis. Namely, that beliefs about opponents' rationality matter and that pessimistic beliefs could be the cause of observed overcapacity in KS games (both being aware of each others experience level). The implicit assumption being that experienced players can be expected to play more rationally - makes fewer mistakes - than inexperienced ones.

2.2 Experimental procedures

In three separate sessions (A, B, C), sixty subjects took the roles of firms in a duopoly market. Each subject played the game for 20 periods excluding 2 to 4 non-paying practice periods.

Our first treatment variable is the level of experience. The level of experience is measured by the number of periods played so far. We say that a subject is *inexperienced* when he is in the first phase of the game (periods 1-10) and we use the subscript $_1$ to indicate that a subject (A_1, B_1 or C_1) is inexperienced. Similarly a subject is *experienced* when he is in the second phase of the game (periods 11-20) and we use the subscript $_2$ to indicate that a subject (A_2, B_2 or C_2) is experienced. The experiment is designed so that subjects with different levels of experience play against each other. The experiment proceeds as follows (see figures 1 and 2). In

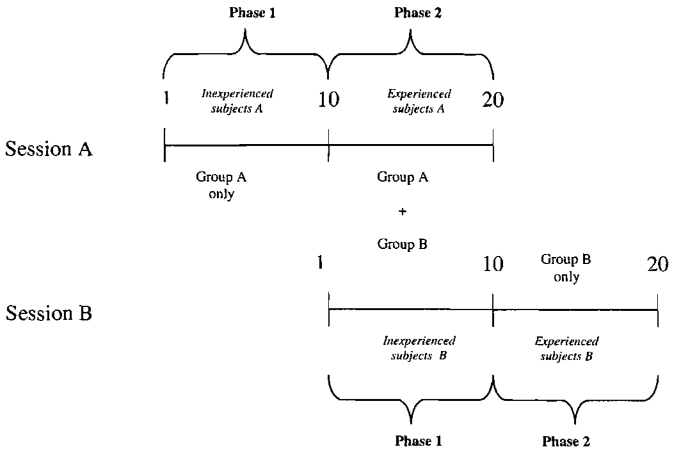

Figure 1: Experimental procedure for sessions A and B

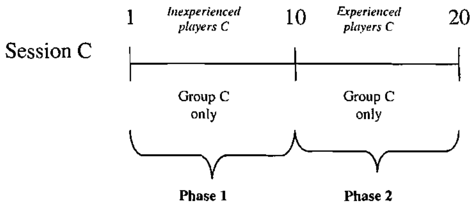

Figure 2: Experimental procedure for session C

their first phase (periods 1-10), subjects A_1 (as well as subjects C_1) play internally, against subjects with the same experience level. In their first phase (periods 1-10), subjects B_1 meet subjects A_2 who have played the game for 10 periods already, i.e., inexperienced players B_1 meet experienced players A_2. In their second phase (periods 11-20) subjects B_2 (as well as subjects C_2) play internally, against subjects with the same experience level.

The matching procedure is the second treatment variable we emphasize. A random-matching procedure was used for group A and group B, where subjects played against a new randomly selected opponent in each round and never against the same opponent twice. A fixed-group procedure was used for group C, where the matchings were not changed during the twenty periods. The subjects were informed of the matching rule.

Table 1: Five treatments

	Random matching	*Fixed matching*
Inexperienced only	A_1A_1	C_1C_1
Experienced only	B_2B_2	C_2C_2
Experienced and Inexperienced	A_2B_1	-

Thus, we employed five treatments (see Table 1). In phase 1, Group A's subjects play among themselves (treatment A_1A_1). The notation refers to a member of group A in phase 1 playing against members of group A, also in phase 1. Similarly, in treatment B_2B_2 members of group B in phase 2 play against members of group B, also in phase 2. In treatment A_2B_1 members of group A in their second phase meet members of group B in their first phase. Finally treatments C_1C_1 and C_2C_2 refer to the first and second phase of play within group C.[6]

The experiment was conducted in May 2002 at the Stockholm School of Economics.[7] The subjects in the experiment were first year students at the Stockholm School of Economics, and were recruited by e-mail or announcements in classroom. The participants earned, on average, 302kr, with a minimum of 150kr and a maximum of 480kr. One full session lasted about an hour and a half, including time spent reading the instructions. Subjects were paid according to their total profits earned during a sessions plus a 100kr show-up fee. We used an artificial laboratory currency, "experimental dollars" (e$) where 1kr (0.116 US$) equals 50e$.

When the subjects arrived at the laboratory they were randomly seated in front of computer terminals and handed written instructions.[8] Communication between subjects was not permitted throughout the session and the individual workstations were separated so that subjects could not see each other's screens. The experiment was fully computerized with subjects entering choices on their terminals. In each period, subjects observed three different screens. On the *quantity choice screen* each subject entered a quantity of his choice in the interval 0 to 90 with up to two decimals. On the *price choice screen* his chosen output level and current opponent's output level were displayed. He then entered a price level between 0 and 120 with up

[6] C_1C_1 and C_2C_2 are not really two separate treatments. Subjects in group C played in fixed pairs for 20 periods. The separation into two treatments is purely artificial but simplifies the comparison with other treatments.

[7] We used the z-Tree sofware package developed by Urs Fischbacher (2002), Institute for Empirical Research in Economics, University of Zurich.

[8] See the appendix for full text instructions.

to two decimals.[9] The *result screen* then displayed all choices made by him and his opponent and the resulting profits, calculated according to (1). The quantity choice and price choice screens both featured a profit calculator, where subjects could insert different hypothetical values for their own and their opponent's quantities and prices and compare the resulting profits.

The primary sessions, with randomly matched opponents were run on two separate days. Each day, 12 participants played as type A players and 12 played as B. In the first day, one subject had to leave the experiment, but was replaced by an assistant. All observations from that subject are skipped, before and after the substitution. This should not have had any impact on other players actions since this subject played against other subjects in a different room and his opponents where neither informed about the switch nor had means of learning about it. Data from trial periods was not used in the analysis except in instances with lagged variables or differenced variables, in which case we use the last practice period to calculate the first period differences.

3 Experimental results

The random-matching procedure, used in all the principal sessions, requires the use of subject-level data instead of market-level data as in David (1999), Muren (2000) and Anderhub et al. (2002). Subject level data are also more useful for our purposes as subjects with different levels of experience are paired together in treatment A_2B_1. Figure 3 shows, for each period and group, the mean of chosen capacities and prices. In should be remembered that subjects in groups A and B played against a different group of opponents in periods 1-10 from those played against in 11-20. Subjects in group A first played for 10 periods against other subjects in group A and then another 10 periods against members of group B. In their first 10 periods, subjects in group B faced subjects in group A who had already played the game for 10 periods. Then in their last 10 periods they played internally (see figure 1).

In the first five periods, the average capacity level in groups B and C is close to half of the competitive output level, or 45. Subjects in group A chose even higher levels, 52 on average. The per-period averages decline rapidly in periods 6 to 10 and level off after that. In the last 5 periods average capacities are between 35-37,

[9] The allowable quantity and price ranges correspond to all rationalizable strategies (Pearce 1984).

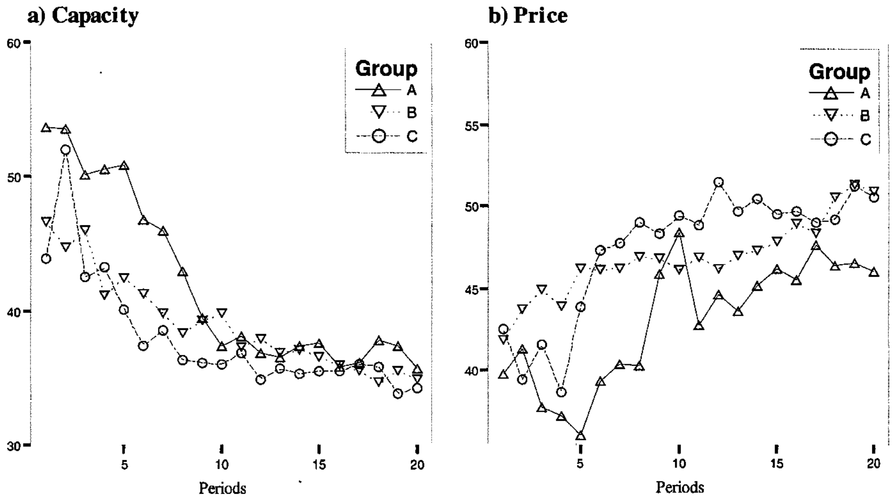

Figure 3: Mean capacity and price, by period and group

depending on the group. Average capacity is higher in group A than in group B in almost all periods. Groups B and C show similar patterns, though B has slightly larger capacities on average. These patterns are consistent with our main hypothesis that players facing inexperienced opponents tend to choose higher capacities than when facing experienced opponents.

Histograms of capacity choice in groups A and B (see figures 8 and 9 in the appendix), show considerable dispersion in the first periods and slow convergence to a bimodal distribution, with modes at 30 (the Cournot output) and 40, where the frequency of capacity levels around 40 is about twice as high for group A than B in the last few periods.[10]

Let us now turn to testing the formal hypotheses that should help us to answer the three following questions:

1. Do we replicate the results of earlier experimental KS oligopolies, i.e., do subjects choose capacities significantly above (and prices below) Cournot levels?

2. Do subjects respond to their opponents' level of experience? In particular, do players facing inexperienced opponents tend to choose higher quantities and lower prices than when facing experienced opponents.

[10]Anderhub et al. (2002) report a similar pattern.

3. Can an intertemporal strategic motive, such as an attempt to become a Stackelberg leader, be an alternative explanation for observed high capacity levels?

The following regression model, adopted from Noussair, Plott & Riezman (1995), is helpful in answering all three questions. Where x_{it} is the observed capacity or price choice of individual i, we estimate

$$x_{it} = \beta_i \frac{1}{t} D_i + \beta_A \frac{t-1}{t} D_A + \beta_B \frac{t-1}{t} D_B + \beta_C \frac{t-1}{t} D_C + \varepsilon_{it} \qquad \text{(I)}$$

where D_i is a subject dummy variable and D_A, D_B and D_C are group dummies. The weights in front of the subject dummy variables ($\frac{1}{t}$ in front of D_i) are greater for observations in early periods then later periods. The weights on the group dummies ($\frac{t-1}{t}$) are low in early periods and higher in later periods. This setup is based on the assumption that while individual behavior may diverge considerably within each group, such deviations are less profound in later periods. The advantage of this method is that we can use the whole dataset to draw conclusions about treatment effects, while still controlling for individual deviations to a large extent.

Equation (I) is estimated for all subjects in the three groups simultaneously.[11] The period index t refers to the number of times the game is played in each phase of the sessions. First we run the regressions for all subjects' first phase. This represents group A in treatment A_1A_1, group B in treatment A_2B_1 and group C in treatment C_1C_1. The second regression is for the second phase and concerns group A in treatment A_2B_1, group B in treatment A_1B_2 and group C in treatment C_2C_2. The parameter estimates are corrected for first order autocorrelation and standard errors for potential heteroscedasticity by White's method. Parameter estimates are listed in table 2.

To answer the first question, we test if the null hypothesis that the group dummies are equal to the Cournot prediction can be rejected. The group dummies measure the central tendency in each group, putting more weight on later periods, while allowing individual effects, particularly in the early periods, to be picked up by the subject dummies. The following single-sided F-tests:

$$\text{Quantities:} \quad H_0 : \beta_g = 30 \quad H_1 : \beta_g > 30$$
$$\text{Prices:} \quad H_0 : \beta_g = 60 \quad H_1 : \beta_g < 60$$

[11] The exception is subject 6 in group A. Its data was skipped for reasons explained above.

Table 2: Regression results

	Model I				*Model II*	
	Phase 1		*Phase2*		*Phase 1*	*Phase2*
Parameter	*Capacity*	*Price*	*Capacity*	*Price*	*Capacity*	*Capacity*
β_A	43.15	42.15	36.23	46.54	42.99	36.56
	(1.38)	(1.19)	(1.11)	(1.05)	(1.13)	(0.55)
β_B	39.63	46.82	35.76	49.57	39.43	35.47
	(1.35)	(1.16)	(1.09)	(1.02)	(1.11)	(0.54)
β_C	38.67	46.62	34.39	50.42	-	-
	(1.91)	(1.64)	(1.54)	(1.45)	-	-
β_{EQ}	-	-	-	-	0.146	0.146
	-	-	-	-	(0.054)	(0.13)
R^2	0.38	0.20	0.41	0.31	0.44	0.47
n	590	590	590	590	470	470
$p^*_{Courn.}$	0.00	0.00	0.00	0.00	-	-
$p^\dagger_{A \text{ vs. } B}$	0.04	0.01	0.23	0.32	0.01	0.08
$p^\ddagger_{A \text{ vs. } C}$	0.03	0.01	0.38	0.02	-	-

Estimation and testing of models (I) and (II) with capacities and prices as dependent variables. Model (I) is corrected for first order autocorrelation. Standard errors are corrected for heteroscedasticity (White's method).

* The critical level of significance (p-value) for the single-sided test of $\beta_i = (30, 60)$.

† The critical level of significance (p-value) for the single-sided test of $\beta_A = \beta_B$.

‡ The critical level of significance (p-value) for the single-sided test of $\beta_A = \beta_C$, periods 1-10 and $\beta_B = \beta_C$, periods 11-20.

where $g \in \{A, B, C\}$, were both rejected at the 0.01 level of significance. Table 2 reports the p values in each case (see $p_{Courn.}$). We can summarize the answer to the first question as follows.

Result 1 *Capacities and prices fail to converge to the Cournot values,* 30 *and* 60 *respectively in all three groups.*

This is consistent with earlier experimental results, that aggregate market output converges to a capacity significantly above the Cournot level, both in triopoly markets (Davis, 1999 and Muren, 2000) and duopolies (Anderhub, 2002).

The second question is more interesting. Namely, do subjects adjust their behavior in response to their opponents' level of experience. In particular, do they choose lower quantities when playing against experienced subjects, relative to when they play against inexperienced subjects. And similarly, do they choose higher prices, on average, when playing against experienced subjects.

First, we test the null hypothesis of equal medians of capacities and prices in each period against the one sided alternative of quantities being larger, and prices and profits lower in group A than in B.

In the first phase (periods 1-10) when subjects are inexperienced, the Wilcoxon-Mann-Whitney test (WMW) rejects the null hypothesis for groups A and B, in 4 (7) cases out of 10, at the 5% (10%) level of significance. With the alternative H_1 that the median in group A is lower than in B the H_0 of equal medians is only rejected once (in period 10). In the case of prices, the H_0 is rejected 7 times out of 10 at the 5% level of significance.

In the second phase (periods 11-20), when subjects are more experienced, the null hypothesis is only rejected in one case at the 10% significance level, in the case of quantities. When it comes to prices, the H_0 is rejected 3 times out of 10 at the 5% level of significance and 6 times out of 10 at the 10% level.

The small number of observations in each period (23 for group A and 24 for group B) may cause the limited number of rejections of the null hypothesis. It is therefore interesting to see if we get clearer results when data from all periods within each phase are pooled together in a single regression dataset. Here we report on tests based on the regression model (I), but almost identical results were produced using a two-factor fixed-effects panel regression.[12] The hypotheses tested are the following:

$$\text{Quantities:}\quad H_0 : \beta_A = \beta_B \quad H_1 : \beta_A > \beta_B$$
$$\text{Prices:}\quad H_0 : \beta_A = \beta_B \quad H_1 : \beta_A < \beta_B$$

where β_A and β_B are estimates of the converging values in group A and B respectively. The resulting critical p-values of the F-tests are reported in parentheses in table 2. In the first phase, the hypothesis of $\beta_A = \beta_B$ is rejected for both variables at the 5% level of significance. In the second phase, however, the hypothesis is rejected for prices but not for quantities.

It is apparent from figure 3 that subjects have a tendency to choose rather high capacities in early periods and that capacities are larger on average in group A than in group B. While this is consistent with our hypothesis, that the opponent's experience matters, there may be other factors influencing the result, which might

[12]Such a model has more general individual and time effects but the tests are less intuitive.

distort the comparison. Subjects might, for instance, form beliefs about (the central tendency of) future opponents' capacity choices based on past observations and choose their strategy accordingly. In that case, we should expect subjects who have observed relatively high capacities in the past to choose lower capacities than average in the future. This behavior is generally defined in the literature as fictitious play (see Fudenberg and Levine, 1998, especially chapter 2). To allow for such adaptive learning, we estimate a second model for groups A and B

$$x_{it} = \beta_i \frac{1}{t} D_i + \beta_A \frac{t-1}{t} D_A + \beta_B \frac{t-1}{t} D_B + \beta_{EQ} \times \left(EQ_{it} - \overline{EQ}_{\cdot t,g}\right) + \varepsilon_{it} \qquad \text{(II)}$$

where the added variable EQ_{it} is a measure of what subject i expects his opponent's capacity to be in period t, and corresponds to the weighted average capacity observed from past opponents. The weights are chosen so that recent observations weigh more heavily than old ones. $\overline{EQ}_{\cdot t,g}$ is the average of EQ_{it} for player i's group (either A or B). The deviations form is preferred for two reasons. On the one hand, this independent variable shares a common trend with the dependent variable. Using it in the regression in levels would give spurious results. On the other hand, a priori we can expect EQ_{it} to be larger in group A than in group B, which causes multicollinearity with respect to the group dummy variables. The hypothesis $\beta_A = \beta_B$ is rejected more strongly in model (II) than in model (I). The sign on the parameter β_{EQ} is not consistent with the the fictitious play, but several different explanations are possible, e.g., imitation or reinforcement learning (see for example, Rassenti et al. ,2000, for a description of different models of learning in a context of Cournot experiments). The conclusions can be summarized as follows.

Result 2 *Inexperienced subjects (Phase 1) choose significantly higher quantities and lower prices, on average, when playing against similarly inexperienced subjects than when playing against subjects with more experience.*

Result 3 *Experienced subjects (Phase 2) choose significantly lower prices, on average, when playing against inexperienced subjects than when playing against subjects with similar experience as themselves. The difference in average quantities is marginally significant.*

These two results raise the question that, even while opponents' experience affects capacity choice negatively, the effect is decreasing in own experience. The simple example in section 2 did not account for any interaction between a player's own experience and the experience of his opponent. The more detailed model discussed in the next section, on the other hand, allows for varying degrees of experience. The predictions turn out to be consistent with these results.

The comparison between fixed- and random matching treatments allows us to evaluate the third question stated above. One suggested cause of the large capacities selected in KS-experiments is that subjects may be trying to bully their opponents to accept disproportionately small output levels (Davis, 2000). Indeed, if a player succeeds in convincing his opponent that he will choose a high capacity regardless of what he does, the opponent's best response is to reduce his own capacity, as if the bully was a Stackelberg leader and had already committed to a high capacity level. This strategy is never a Nash equilibrium if the game is played for a finite number of periods. Still, non-equilibrium intertemporal strategies are frequently observed, perhaps because some subjects fail to grasp the immanent breakdown of such schemes in the final period. Or, more subtly, a rational player may suspect that his opponent fails to understand this reasoning. However if subjects never meet the same opponent more than once, there is no point in adopting intertemporal strategies.

To test if there is evidence of such strategic behavior, we compare the choices of group A in treatment A_1A_1 to C in treatment C_1C_1 on the one hand, and group B in treatment B_2B_2 to C in treatment C_2C_2 on the other. The level of experience (in terms of periods played) is the same in each case. Only the matching procedure is different, random (perfect stranger) for groups A and B and fixed for group C. For the capacity variable we test the following hypotheses:

$$\begin{array}{lll} \text{Phase 1:} & H_0 : \beta_A = \beta_C & H_1 : \beta_A < \beta_C \\ \text{Phase 2:} & H_0 : \beta_B = \beta_C & H_1 : \beta_B < \beta_C \end{array}$$

while in the case of prices and profits the inequality in the H_1 hypothesis is reversed. The H_0 hypothesis is never rejected against the one-sided alternative of median capacity being smaller, and prices and profits greater, in groups A and B in respective phases and group C. The few p-values for the WMW test that show significant difference (see table 4), apply to the opposite one-sided H_1 hypothesis. That is, in a majority of the first phase periods we find that median capacity is significantly larger in group A than in group C. We summarize the answer to question 3 as follows.

Result 4 *We find no support for the strategic motive, such as an attempt to become a Stackelberg leader.*

4 Further analysis using quantal response equilibrium

So far we have only presented a simple example of how an opponent's experience level matters for the outcome of KS games. While results 2 and 3 indicate that a more complete theoretical setup is needed to better understand the experimental results, in particular, a framework that allows for varying degree of player's experience. In this section we apply the quantal response equilibrium (QRE), developed by McKelvey & Palfrey (1995) to the KS game and show how important predictions of the model fit well with the experimental data.

4.1 Logit-AQRE applied to KS game

The QRE framework can be looked at as an extension of Nash equilibrium. Players are not expected to play best responses with probability one, but rather probabilistic best response functions. The probability with which each strategy is played is related to the associated expected payoff. While in Rosenthal's (1989) model of bounded rationality in games the probability put on a particular strategy is specified as a linear function of expected payoff, the QRE derives choice probabilities from quantal response statistical models, as the name suggests. Each element in a player's payoff function is subject to an error, usually assumed to be identically and independently distributed. A corresponding equilibrium concept for extensive form games is the agent quantal response equilibrium (AQRE) (McKelvey and Palfrey, 1998). This extension uses the concept of the agent-strategic form where, in each information set, a separate agent plays on behalf of the relevant player (Selten 1975). The crucial assumption is that errors in the payoff function are independently distributed, even for different agents of the same player.

The model. We assume that errors are identically and independently log-

Weibull distributed so that the quantal response functions take the logit form,

$$b_{i,q_i}^* = \frac{e^{\lambda_i \overline{\pi}(q_i, b^*)}}{\sum\limits_{q_i' \in A_q} e^{\lambda_i \overline{\pi}\left(q_i', b^*\right)}}, \quad i \in \{1, 2\} \tag{5}$$

for $q_i \in A_q$ and

$$b_{i,p_i|\mathbf{q}}^* = \frac{e^{\lambda_i \overline{\pi}(p_i, b^*)}}{\sum\limits_{p_i' \in A_p} e^{\lambda_i \overline{\pi}\left(p_i', b^*\right)}}, \quad i \in \{1, 2\} \tag{6}$$

for $p_i \in A_p$, where b_{i,q_i}^* is the equilibrium probability of player i selecting a capacity level q_i and $b_{i,p_i|\mathbf{q}}^*$ the probability assigned to the price level p_i conditional on both player's capacity choices. The complete strategy profile is denoted by b^*. The term $\overline{\pi}(q_i, b^*)$ describes the expected payoff when the player in question chooses the capacity level q_i with probability one while the opponent's strategy and own price strategy follows b^*. Similarly, $\overline{\pi}(p_i, b^*)$ is the expected payoff when the strategy profile b^* is played, except own price is p_i with probability one. The expected payoff functions are are calculated from (1) assuming that beliefs are consistent with b^*. Finally, λ_i is the logit distribution parameter, a measure of the accuracy with which player i observes his payoff function. The logit-AQRE is found by solving a system of equations (5) and (6) for all information sets for particular levels of λ_i.[13]

Two special cases are particularly interesting. When $\lambda_i = 0$ the errors completely dominate any information about the payoff function and players choose all strategies with equal probability. On the opposite extreme, when $\lambda_i \to \infty$ the errors become negligible, in which case each player chooses his best response with probability one and the unique subgame-perfect equilibrium, the Cournot outcome, appears. These two extremes were combined in the simple example in section 2, where a fully rational player played against someone choosing strategies at random.

When a particular experiment is repeated, subjects gain experience and they can be expected to make more precise estimates about payoffs resulting from different strategies. The precision with which subjects observe their payoffs can be affected by many factors, but it is reasonable to expect that the level of experience monotonically affects precision. The experiment is designed bearing this in mind, thus subjects with different levels of experience are paired while other factors remain constant. What is not reasonable to assume is that subjects behave as if they observe their

[13] See McKelvey & Palfrey (1998) for a complete exposition of the AQRE.

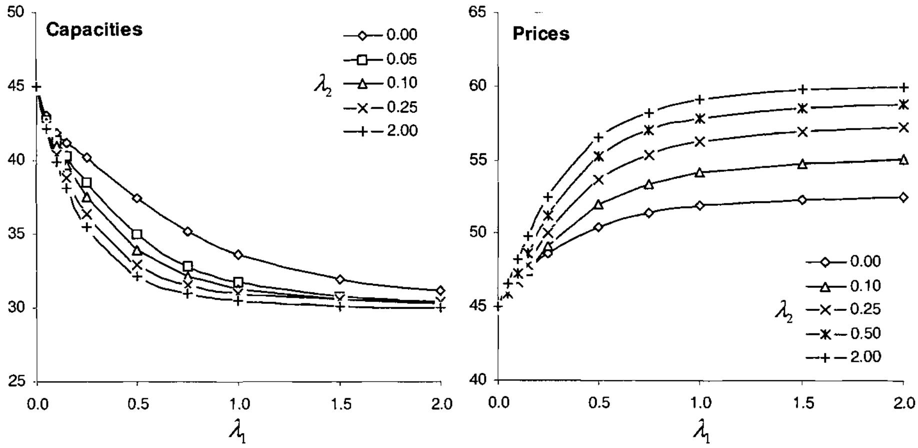

Figure 4: Mean capacities and prices in logit-AQRE equilibrium

payoffs with either perfect or minimal precision, as in the example. The AQRE framework allows us to study the outcome of the game when the two players have asymmetric but intermediate values of λ.

Simulated results. It turns out to be extremely difficult, if not impossible, to find a closed form solution to this problem. The main reason being discontinuities in the payoff function (1). The problem is, however, easily solved numerically[14] with a relatively dense approximation of the action space used in our experiment, $A_q = A_p = \{10, 15, 20, ..., 80\}$, yielding a manageable number of nonlinear equations, $2 \times (15 \times 15 + 1) \times 15 = 6780$. For computational reasons we need to restrict the action space to multiples of five.[15]

The means of capacities and prices generated by the equilibrium strategies of an arbitrary player 1 are shown in figure 4, for several levels of player 1's precision level, λ_1, and player 2's (his opponent's) precision level, λ_2.[16] Each curve shows how the relationship between player 1's average capacity and his precision level, for a given level of the player 2's precision level.

[14]The program was solved using GAMS/PATH mixed complimentarity problem solver. The code is available on the web at http://www.hi.is/~jonthor.

[15]While continuous space techniques exist for normal form games,(Anderson, Goeree & Holt 1998) we are unaware of similar tools for extensive form games. The results do not seem to be too sensitive to the discreet approximation of the action space.

[16]The numerical values of the λ's are specific to the model and can only be compared in relative terms. The model is not solveble for λ's much larger than 2.

Observe from the left hand graph in figure 4 that player 1's average capacity decreases in his own precision, and seems to converge toward the Cournot output level. This is especially true when the opponent's experience level is high. In other words, when both players observe their payoffs with high precision the logit-AQRE converges to the unique subgame-perfect equilibrium. An increase in λ_2 corresponds to a downwards shift in figure 4, which implies that player 1's average capacity is decreasing in λ_2. This effect is important for intermediate λ_1 but very small for low or high λ_1.

From the right hand graph in figure 4 we can see that average price increases with player's own precision (λ_1) but does not converge to the Cournot outcome when the opponent lacks precision (λ_2 is low), as opposed to capacity. An increase in λ_2 has a positive effect on the expected price of player 1 and the effect is strengthened with an increase in λ_1. The standard deviation of capacities and prices decrease in both λ_1 and λ_2 as expected and need not be discussed in detail.

The bias, towards larger capacities and lower prices when the opponent is thought to have limited rationality, seems robust to changes in levels of the precision parameters λ_1 and λ_2. It is also qualitatively consistent with the regression analysis presented in table 2. Recall from result 3, that the difference between capacities chosen by experienced players when playing against experienced opponents on the one hand, and inexperienced players on the other, was not significant while mean and median prices were. Figure 4 illustrates quite well, that this may be expected, there being a close link between experience and individual rationality. The variability in average capacity caused by an opponent's experience level is very small when player's own experience level is high. Thus, it may be easier to detect the effect of an opponent's experience level in price decisions rather than capacity decisions.

The reader might wonder, at this point, if the bias depends more on the particular specification of the action space rather than the players' level of rationality. As it turns out, both matter. If, for instance, we select the action space such that the expected quantities and prices are equal to the Cournot outcomes, when $\lambda_1 = \lambda_2 = 0$, the relationship between mean of capacity and λ_1 is no longer monotonic. However, for any $\lambda_1 > 0$ the expected capacity is larger and the price lower than the Cournot outcome predicts. The pattern of the bias is affected though, especially in the case of prices. We deal with this issue in more detail in appendix A.

4.2 Estimating the AQRE model- Data analysis

The predictions of the logit-AQRE fit qualitatively well with the experimental results of section 3. The question remains, however, if the predictions are quantitatively accurate. In seach of an answer we look at two things. We estimate the precision parameters (λ) that best fit with the experimental data and compare the predicted and actual average capacities and prices.

For each treatment (excluding C_1C_1), we estimate the precision parameters (λ) that maximize the following likelihood function,

$$ln\mathcal{L} = \sum y_{i,t}\left(q_i, q_j, p_i\right) \times \ln\left(b_{q_i}\left(\lambda_1, \lambda_2\right) + b_{p_i|q}\left(\lambda_1, \lambda_2\right)\right). \tag{III}$$

The summation applies to subjects, a subset of periods and all possible combinations of q_i, $q_j \in A_q$ and $p_i \in A_p$. The index variable $y_{it}(q_i, q_j, p_i)$ takes the value 1 if subject i selects the quantity q_i and price p_i in round t while his current opponent chooses q_j or else the value zero.[17] The b functions are the equilibrium response functions as defined in (5) and (6). Each treatment is broken down into five experience levels with two periods in each. In treatments A_1A_1 and B_1B_1, where all subjects have the same amount of experience we estimate a single precision parameter, λ_A or λ_B respectively, while in treatment A_2B_1 a separate parameter is estimated for each group. The estimates together with the log-likelihood values ($ln\mathcal{L}_{\text{AQRE}}$) are reported in table 5.

The estimates for λ_A and λ_B generally increase with the experience level (see Figure 5) reflecting the tendency for subjects to choose strategies with higher payoffs as they get more experienced in playing the game. The learning process can vary substantially between individuals and depend on things other than the number of periods played. It is, for instance, interesting to note that λ_B is higher than λ_A for any given level of experience. It is doubtful, though, that the opponent's experience level affects the speed of learning, since the difference in λ is more or less of the same magnitude for different experience levels. A more plausible reason is that inexperienced subjects in group B, knowing that they will face experienced players A, put more effort into finding their best strategy, compared with similarly experienced A players who meet similarly inexperienced players.

Comparison of $ln\mathcal{L}_{\text{AQRE}}$ to the log likelihood of the random model $ln\mathcal{L}$ (i.e., when

[17] Selected quantities and prices are rounded up or down to the nearest point in the discrete action space.

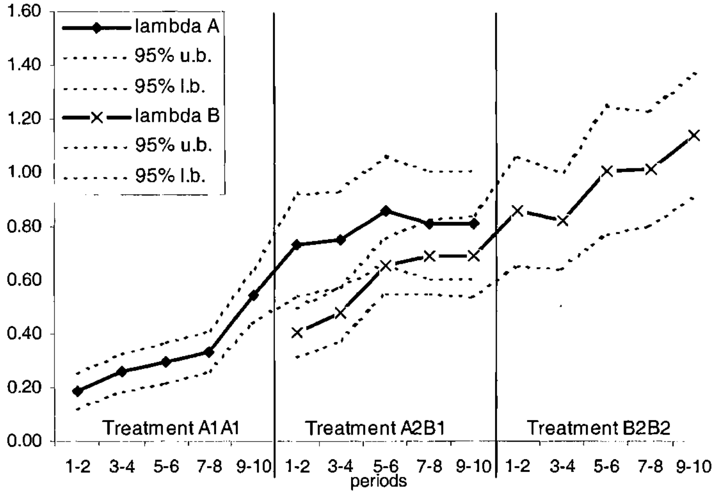

Figure 5: Estimated λ and 95% confidence intervals

$\lambda_A = \lambda_B = 0$) for each row in table 5 in turn, suggests improved fit when subjects gain experience. In table 6, we compare the predictions based on the estimated logit-AQRE model for each experience level, and the actual choice (adjusted for the discrete action space). It is clear that, even though the model provides fairly good qualitative predictions, it systematically underpredicts quantities and overpredicts prices. The predicted standard deviations, however, are close to the actual levels.

The logit-AQRE is a better prediction of behavior than three alternative models we considered, which are similar to those used by Rassenti et al. (2000) in the context of Cournot games. In the *partial Cournot equilibrium model*, a player chooses the Cournot output as his capacity level with a specific probability or alternatively, any strategy at random. In the *partial fictitious play model*, each player chooses a capacity, which is a best response to a weighted average of previously observed capacity choices made by opponents, with a certain probability or alternatively, any strategy at random. The weights are chosen so that recent observations weigh more heavily than old ones. Finally, in the *partial imitation model*, subjects imitate the capacity choice they have observed resulting in the highest profit. These models are all called partial models, as they only differ with respect to the capacity choice. Because of the complexity of price strategies, a simple ad-hoc price strategy is chosen.[18] All three models have two parameters, one for the probability of choosing the described capacity strategy, θ_q, and one for the probability of choosing the resulting market clearing price, θ_p. The respective log likelihood values are displayed in columns 5-7 in table 5.

All of these models are rather crude, and their main purpose is to provide some reference for the AQRE model. As it turns out the AQRE model performs better than the alternative learning models. All these models (excluding the AQRE model) perform similarly well in the treatments when subjects have similar experience. In the A_2B_1 treatment however, the imitation model is clearly the second best model, after the AQRE model.

5 Conclusion

The purpose of this paper is to improve our understanding of why subjects consistently choose capacities above, and prices below, the predicted subgame-perfect equilibrium in experimental Kreps and Scheinkman games. We argue that players' perceptions about their opponents skill, or level of rationality, are important in this context. Using experience in playing the game as a proxy for the level of rationality in our experimental design, we find that, capacities are relatively higher when opponents' level of experience (number of periods played) is relatively low and that prices are relatively low when opponents lack experience.

We explore the experimental results further using the quantal response equilibrium framework. Predictions, based on a logit agent-form quantal response equilibrium model, turn out to be qualitatively consistent with experimental findings, some of which seem inconclusive at first.

Since the Cournot model is often used as a benchmark in applied economics, e.g., in competition policy where the Cournot model is the theoretical foundation of the use of concentration indices in merger guidelines, the results obtained are highly relevant. They suggest that performance in oligopolies depends on the experience of

[18]For all learning models, we assume that subjects choose the market clearing price with a minimum level equal to the marginal cost, $p_{mc} = \max(120 - (q_1 + q_2), 30)$, plus/minus 2.5, with probability θ_p or choose a random price strategy with probability $(1 - \theta_p)$. While the market clearing price is only a Nash equilibrium for sufficiently low capacities, it is probably a better approximation in this simple framework than the average price of the respective mixed strategy equilibrium. While the average price of a mixed strategy equilibrium can surely go below the marginal cost, which is sunk at the pricing stage, there were practically no such cases in the entire experiement.

market participants and how well participants are informed about their competitors' experience.

It is somewhat disappointing that the logit-AQRE model, as specified here, does not give quantitatively accurate predictions. The observed deviations are much larger than predicted by the model, indicating that the current model specification is too restrictive. At least two extensions seem worthy of further research.

1) A closer inspection of the distribution of capacity choices, as shown in figures 8 for group A and 9 for group B, suggest that there may be considerable heterogeneity within each group. The distribution of capacity is bimodal for a reasonably experienced subject pool. In the last two periods of play, almost a third of subjects in group B chose the Cournot output level 30, while another third chose a capacity level close to 40. Allowing for different levels of rationality within each group would account for this, and possibly increase the level of the predicted bias.

2) Extending the AQRE model to allow for inconsistent response functions is another interesting alternative. Weizsacker's (2001) extension of the normal form QRE allows for response functions which depend on perceived opponent's choice distributions which do not necessarily have to be consistent with the opponents actual equilibrium strategy. Estimation on experimental data suggests that perceptions are quite frequently biased in the direction of underestimating the rationality of other players. In the logit quantal response framework this amounts to a downwards bias in players perception of their opponents' precision level. If the same bias appeared in the KS model the predictions of such a model would probably be closer to the actual outcome, for average quantities should rise given that beliefs about an opponent's precision level decrease, as shown in figure 4.

Appendix A - Choice of Action Space

If players randomize completely, the average capacity is determined by the mean of the action space. In most conceivable configurations of the KS model, the average of all feasible capacity levels is higher than the Cournot output, while the opposite is true for prices. This fact might affect the prediction of the logit-AQRE model. It is therefore interesting to compare the above predictions to the case where the action space is symmetric around the Cournot outcomes, $A_q = \{0, 5, ..., 60\}$ and $A_p = \{30, 35...90\}$. In this setup the expected capacity and price chosen by a totally clueless player (with $\lambda_1 = 0$) is simply the Cournot outcome. Figure 6 illustrates average capacity and price choices in the logit-AQRE equilibrium profile. With a symmetric action space, average capacity is no longer uniformly decreasing in own precision level (λ_1). For positive levels of λ_2 it first increases and then decreases. Furthermore, capacity only converges to the Cournot output level when both λ_1 and λ_2 increase simultaneously. The case of prices is more complicated, as average price is not monotonic with respect to λ_2 either.

In the simple example presented in section 2, the action space was intentionally chosen to be symmetric around the Cournot equilibrium in order to eliminate additional bias caused by the distribution of quantity and levels in the action space. A symmetric action space would be difficult to impose on our experiment[19] and we can expect a further bias towards high capacities, in the case of inexperienced subjects, for this reason. It is very hard, if not impossible, to control for how subjects think about the action space. Judging from how subjects started out with average capacities close to 45, the average of rationalizable capacity levels, we believe the specification used is appropriate. The comparison of these two configurations is still helpful. It suggests that the presence of a bias towards larger capacities and lower prices does not seem to be caused by the choice of action space, though it is an important determinant of the shape of the bias with respect to the level of players' rationality and their perceptions about the rationality of others.

[19] Cournot equilibrium prices and quantities are rarely in the center of what is natural to perceive as feasible prices and quantities. Without any knowledge of what subjects perceive to be a natural action space we specify the action space as those actions belonging to all rationalizable strategies (Bernheim 1984).

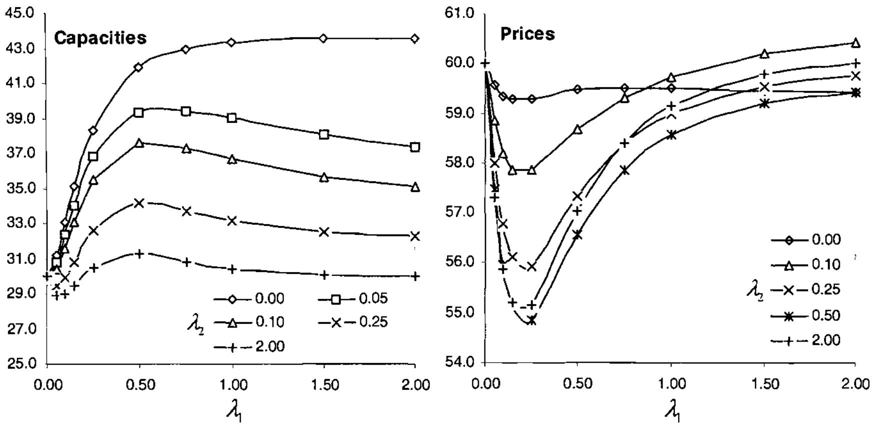

Figure 6: Mean capacities and prices in logit-AQRE equilibrium - Action space symmetric around Cournot outcome

Appendix B - Instructions

{}: group A, []: for group B and, * *: group C

Welcome to this experiment in the economics of decision making, which should take approximately 90 minutes. For your participation you will be paid a minimum of SEK 100, but you can earn much more if you make good decisions. At the end of the session you will be paid, in private and in cash, an amount that will depend on your decisions. Please read the instructions carefully. If you have any questions please raise your hand, and you will be helped privately.

General Rules

This experimental session will consists of several periods. In each period you play the role of a firm which produces a good and sells it in a market.

{One other firm, represented by a randomly selected participant, sells his product in the same market in each period. For the first 10 periods you will play against other participants sitting in this room. You will never face the same participant more than once. After period 10 the experiment will restart, but now you will play against a different group of participants located elsewhere. *Unlike you, these participants have no prior experience of this experiment.* As before, you will only play against each of the new participants once.}

[One other firm, represented by a randomly selected participant, sells his product in the same market in each period. For the first 10 periods you will play against a different group of participants located elsewhere. *Unlike you, these participants have experience of this experiment, they have played the game before.* You will never face the same participant more than once. After period 10 the experiment will restart, but now you will play against other participants sitting in this room. As before, you will only play against each of the new participants once.]

One other firm, represented by another participant, sells his product in the same market. You will play against the same participant in all 20 periods. The true identity of your opponent will not be revealed to you, and neither will your identity be revealed to him.

By making good decisions you can earn profits in experimental dollars (e-dollars). At the end of the session you will be paid SEK 100 plus the e-dollars you have earned at the exchange rate of 1 SEK for every 50 e-dollars. Simply put, the more experimental dollars you earn the more cash you will receive at the end of the session.

In each period you make two separate decisions for your firm. First you decide how much you would like to produce (Q1) and then, after you have observed the production level of your competitor (Q2), you choose your price (P1).

Production stage

At the beginning of each period you decide how many units of the good to produce (Q1). You make your decision by entering a number in the box on the left hand side of the screen and then press OK. **Any positive number between 0 and 90, with up to 2 decimals** is acceptable. (Example: 10, 20.6, and 33.33 are valid but -12, 50.123 are not). Please use a dot (.) as a decimal separator.

The amount you produce has consequences for your profit for that period, since you have to pay a production cost of 30 e-dollars for each unit. Regardless of how much you sell. Note that no inventories can be carried to future periods.

Before you type in your quantity you should think carefully about your choice. You can use the calculator displayed on the right hand side of the computer screen. There you can enter prospective production quantities and prices for your firm and its competing firm, press CALCULATE and observe the results in the table on the lower right hand side. Table 3 explains the columns.

Price stage

When all participants have entered their production levels you will automatically go to the price stage. On the left hand side you can see your own chosen production level as well as your competing firm's production level. You enter a price of your choice in the box below this information and press OK when you are ready. **Any positive number between 0 and 120, with up to 2 decimals** is acceptable. (Example: 10, 20.6, and 33.33 are valid but -12, 50.123 are not). Please use a dot (.) as a decimal separator. You may want to do some more calculations before you set your price. You still have the calculator on your right hand side, but this time you can only alter the prices (P1 and P2). The previously chosen quantities (Q1 and Q2) are fixed at this stage.

How much you sell is determined by your price (P1) and its relation to your competitor's price (P2). Consumer demand is calculated by a computer program and follows a simple equation

$$D = 120 - P.$$

where D is demand and P is a price. This means for instance that at the price 0 consumers are willing to purchase 120 units of the product. At a price of 25.5 consumers are willing to purchase 94.5 units. There is no demand for the product at price levels equal to or greater than 120. Figure 7 illustrates demand and unit cost.

Consumers strictly prefer buying from the firm offering the lower price. Hence, the firm with the lower price will sell all its production up to the demand level at that price. The firm with the higher price can only sell the product to consumers that are not supplied by the lower pricing firm, and never more than the demand level at its price, or its produced quantity. If both firms choose the same price, demand will be split equally between them up to the capacity limits (the respective production levels).

Table 3: Calculator table legend

Q1	Your production
Q2	Competitor's production
X1	Your sold quantity
X2	Competitor's sold quantity
P1	Your price
P2	Competitor's price

Example 1: Say that Q1 = 35, Q2 = 45, P1 = 45 and P2 = 55. Since demand at the lower price level is 75, you (firm 1) can sell all your produced quantity. Your revenue is $45 \times 35 = 1575$ and your total cost is $30 \times 35 = 1050$. Your profit is $1575 - 1050 = 525$. Your opponent (firm 2) can only sell 30 units. The demand for his product equals $120 - 55 = 65$, by the demand equation. From that we have to subtract what is already supplied by your firm, or 35 units. Hence, he sells $65 - 35 = 30$ units at the price of 55. His revenue is $55 \times 30 = 1650$, his total cost is $45 \times 30 = 1350$ and he makes a 300 e-dollar profit.

Example 2: Say that $Q1 = Q2 = 15$ and $P1 = P2 = 55$. Demand at this price is greater than the sum of the production levels but you can only sell what you produce. Your profit is $55 \times 15 - 30 \times 15 = 375$.

Result display

When all participants have entered their prices the result display will appear. You can then see a summary for that period, for yourself and your competitor. Press continue when you have studied the results.

Periods

To help you familiarize yourself with the computer interface and the calculations, you get to practice for two periods. *The result of these periods will not affect your payoff.*

{Then you will play for 10 periods, ones with each of the participants in your room. Then, after a short break, the experiment restarts, and now you play against the inexperienced participants. Again you go through two practice periods (for the others) and then 10 periods, where you can earn money, against each of the inexperienced participants.}

[The result of these periods will not affect your payoff. Then you will play for 10 periods, ones with each of the experienced participants in the other room. Then, after a short break, the experiment restarts and now you play for 10 periods against participants sitting in your room, which have the same level of experience as you do]

Then you will play for 20 periods for which you can earn money.

Before you leave we ask you to fill in a short questionnaire about the experiment. We will use the time while you complete it to calculate your earnings.

Everything described here is not only valid for you but also for the all other participants in this experiment.

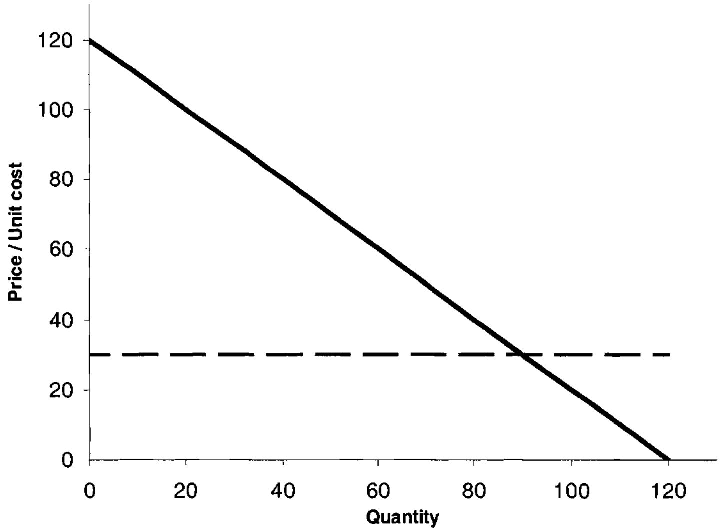

Figure 7: The demand function (solid line) and the unit cost function (dotted line)

Now you should be ready to start the experiment. Please raise your hand if you have any questions. We prefer to answer your questions privately. Good luck!

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Table 4: Summary statistics and non-parametric tests

	A		B		C			
Period[1]	Mean	St.d.	Mean	St.d.	Mean	St.d.	$p^2_{A,B}$	$p^3_{A/B,C}$
a) Quantity choice								
1	53.7	18.7	46.6	15.5	43.9	14.3	**0.076**	**0.082**
2	53.5	19.2	44.8	11.3	52.0	17.2	**0.039**	0.462
3	50.1	15.8	46.0	15.1	42.6	10.1	**0.091**	**0.058**
4	50.6	17.2	41.1	8.0	43.3	6.5	**0.012**	**0.060**
5	50.9	16.5	42.4	14.7	40.1	15.0	**0.011**	**0.014**
6	46.8	16.4	41.3	11.5	37.4	7.3	**0.079**	**0.030**
7	46.0	16.2	39.8	12.2	38.5	10.4	**0.037**	**0.069**
8	42.9	11.7	38.3	8.7	36.4	7.4	0.104	**0.060**
9	39.5	13.0	39.4	7.5	36.2	8.1	0.381	0.202
10	37.4	13.4	39.8	8.2	36.1	7.3	**0.041**	0.355
11	38.2	9.2	37.4	6.0	36.9	8.2	0.401	0.372
12	36.9	9.5	38.0	5.1	34.9	7.8	0.158	0.154
13	36.6	9.2	36.9	5.4	35.7	6.8	0.276	0.292
14	37.4	8.1	37.2	6.0	35.3	6.6	0.337	0.239
15	37.6	9.8	36.6	6.1	35.6	6.9	0.455	0.354
16	35.9	7.7	35.9	6.7	35.6	6.9	0.356	0.503
17	36.2	7.4	35.6	5.2	36.0	7.7	0.498	0.450
18	37.8	7.9	34.7	5.9	35.9	7.2	**0.071**	0.299
19	37.5	7.0	35.6	6.7	33.9	5.8	0.212	0.275
20	35.7	9.0	34.9	5.6	34.3	4.1	0.397	0.335
b) Price choice								
1	39.8	9.6	41.8	10.6	42.5	6.4	0.146	**0.039**
2	41.3	13.7	43.7	9.3	39.4	7.9	**0.042**	0.344
3	37.7	8.6	44.9	12.3	41.5	9.1	**0.017**	0.118
4	37.2	8.9	43.8	10.3	38.7	8.5	**0.005**	0.294
5	36.0	8.0	46.2	11.0	43.9	10.5	**0.000**	**0.015**
6	39.3	11.6	46.1	10.0	47.3	11.3	**0.008**	**0.026**

Table 4: (continued)

	A		B		C			
Period[1]	Mean	St.d.	Mean	St.d.	Mean	St.d.	$p^2_{A,B}$	$p^3_{A/B,C}$
7	40.3	12.4	46.2	8.6	47.7	15.3	**0.010**	**0.062**
8	40.3	12.0	46.9	9.3	49.0	13.2	**0.003**	**0.014**
9	45.9	15.0	46.8	8.1	48.3	13.1	0.159	0.243
10	48.4	12.2	46.1	9.2	49.4	12.1	0.261	0.415
11	42.7	10.6	46.9	7.7	48.8	13.1	**0.027**	0.477
12	44.6	8.6	46.1	7.2	51.5	11.1	0.228	0.107
13	43.6	10.5	46.9	7.3	49.7	11.9	**0.075**	0.373
14	45.2	9.7	47.2	8.1	50.4	11.9	0.172	0.278
15	46.2	11.0	47.8	7.1	49.5	13.0	0.146	0.484
16	45.5	9.4	48.9	9.0	49.7	12.7	**0.081**	0.477
17	47.6	8.1	48.3	6.9	49.0	13.5	0.319	0.386
18	46.4	9.4	50.5	8.6	49.2	13.5	**0.076**	0.348
19	46.5	8.6	51.3	9.6	51.2	11.4	**0.044**	0.444
20	46.0	8.3	50.9	7.7	50.5	7.5	0.035	0.424

[1] The n-th period played by the respective group of subjects

[2] The critical significance level of a single-sided Mann-Whitney test of equal choice distribution in groups A and B

[3] The critical significance level of a single-sided Mann-Whitney test of equal choice distribution in groups A and C (in the first 10 periods) and B and C (in the last 10 periods)

Table 5: Maximum likelihood estimation of the logit-AQRE model

Periods	λ_A	λ_B	$ln\mathcal{L}_{\text{AQRE}}$	$ln\mathcal{L}_{\text{Nash}}$	$ln\mathcal{L}_{\text{Fict.}}$	$ln\mathcal{L}_{\text{Immit.}}$	$ln\mathcal{L}$
			a) Treatment A_1A_1				
1-2	0.19		-205.9	-225.8	-227.3	-226.5	-249.1
	(0.03)						
3-4	0.26		-201.2	-233.5	-233.6	-233.5	-249.1
	(0.04)						
5-6	0.29		-187.5	-217.0	-217.5	-216.6	-249.1
	(0.04)						
7-8	0.34		-196.9	-214.1	-217.3	-217.2	-249.1
	(0.04)						
9-10	0.54		-171.5	-203.4	-217.3	-216.0	-249.1
	(0.05)						
			b) Treatment A2B1				
1-2	0.73	0.40	-345.2	-429.0	-433.1	-406.1	-509.1
	(0.10)	(0.05)					
3-4	0.75	0.48	-341.1	-414.4	-418.6	-395.1	-509.1
	(0.09)	(0.05)					
5-6	0.86	0.65	-310.1	-374.3	-388.2	-362.4	-509.1
	(0.10)	(0.05)					
7-8	0.81	0.69	-315.2	-392.4	-405.8	-362.5	-509.1
	(0.10)	(0.07)					
9-10	0.81	0.69	-321.9	-411.3	-418.2	-370.3	-509.1
	(0.10)	(0.08)					
			c) Treatment B2B2				
1-2		0.86	-154.3	-207.2	-211.9	-202.8	-260.0
		(0.11)					
3-4		0.82	-157.8	-201.3	-208.8	-201.3	-260.0
		(0.09)					
5-6		1.01	-144.8	-188.1	-195.5	-196.6	-260.0
		(0.12)					
7-8		1.02	-144.0	-169.7	-179.9	-167.9	-260.0
		(0.11)					
9-10		1.141	-133.0	-180.9	-186.3	-184.6	-260.0
		(0.12)					

Standard errors in parentheses, estimated by the BHHH method.

Table 6: Actual vs. predicted quantities and prices

	q_A		q_B		p_A		p_B	
	Actual	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*
				a) Treatment A1A1				
1-2	53.9	38.0			40.7	48.5		
	(18.5)	(18.2)			(11.5)	(17.5)		
3-4	50.5	36.1			37.5	50.3		
	(16.2)	(16.3)			(8.6)	(16.4)		
5-6	48.9	35.3			37.5	51.2		
	(16.4)	(15.3)			(10.1)	(15.8)		
7-8	44.5	34.5			40.3	52.2		
	(14.0)	(14.3)			(12.2)	(15.2)		
9-10	38.4	32.3			47.5	55.8		
	(13.1)	(10.6)			(13.7)	(12.4)		
				b) Treatment A2B1				
1-2	37.7	31.5	45.8	33.3	44.1	56.5	42.9	54.7
	(9.2)	(9.0)	(16.6)	(12.6)	(9.7)	(12.2)	(10.0)	(13.2)
3-4	37.1	31.4	43.3	32.6	44.7	56.9	44.5	55.6
	(8.4)	(8.8)	(15.9)	(11.4)	(10.2)	(11.7)	(11.2)	(12.3)
5-6	37.0	31.1	41.7	31.6	46.1	57.9	46.4	57.3
	(8.6)	(8.0)	(16.5)	(9.5)	(10.2)	(10.5)	(10.3)	(10.8)
7-8	37.2	31.2	38.9	31.5	47.0	57.8	46.5	57.4
	(7.4)	(8.3)	(14.6)	(9.1)	(8.8)	(10.6)	(8.8)	(10.7)
9-10	36.7	31.2	39.6	31.5	46.6	57.8	46.7	57.4
	(8.0)	(8.3)	(12.7)	(9.1)	(8.3)	(10.6)	(8.6)	(10.7)
				c) Treatment B2B2				
1-2			37.4	31.0			46.8	58.2
			(11.5)	(8.0)			(7.5)	(9.9)
3-4			37.1	31.1			47.3	58.1
			(11.6)	(8.2)			(7.8)	(10.1)
5-6			36.5	30.7			48.2	58.8
			(11.8)	(7.3)			(8.0)	(9.2)
7-8			35.3	30.7			49.5	58.8
			(11.5)	(7.2)			(7.7)	(9.1)
9-10			35.2	30.5			51.1	59.1
			(11.7)	(6.8)			(8.4)	(8.7)

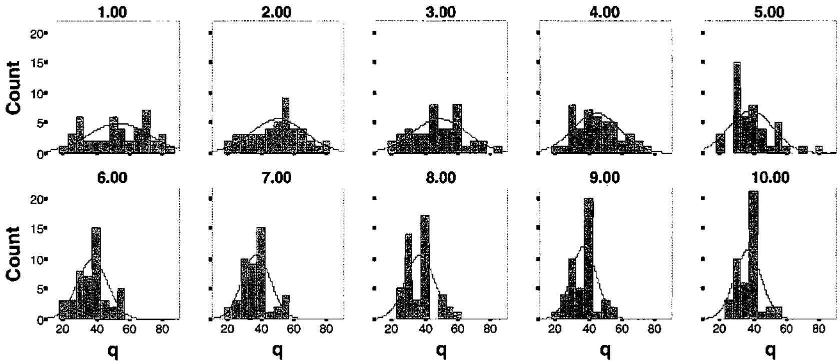

Figure 8: Distribution of quantity choices in group A, each graph indicates a particular experience level (two periods)

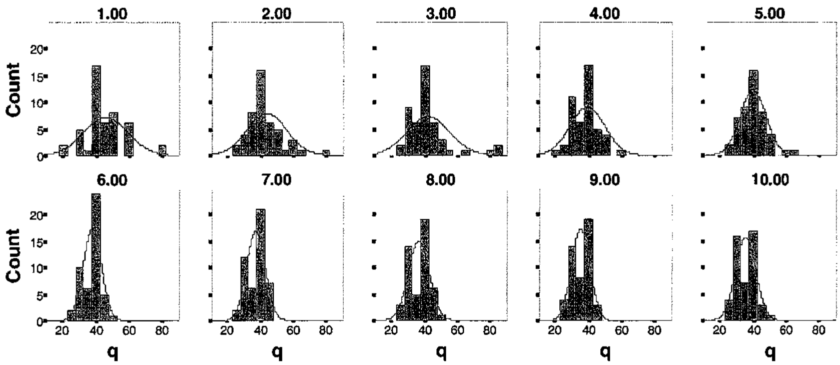

Figure 9: Distribution of quantity choices in group B, each graph indicates a particular experience level (two periods)

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