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Measuring Market Power: The Czech Market of Mobile Operators

Bachelor thesis

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Abstract

The main focus of the thesis is the measurement of market power. Since market power is a determinant of the degree of competition, its measurement is the key feature of competition policy. We present various methods for assessing market power. One of the most famous ones are Lerner index and Herfindahl-Hirschman index, both of which belong to SCP paradigm. Another group of measures are the NEIO models, which provide the empirical analysis of relevant markets.

For the estimation of market power, we have chosen the czech market of mobile operators. We examine the three largest operators (i.e. O2, T-Mobile and Vodafone) in the period 2000-2013. Firstly, the model of Röller and Parker (1997) is used to identify the market's structure. Secondly, we employ the Appelbaum's (1982) industry-level measure to estimate market power.

Keywords: market power, market structure, Lerner index, competition, industrial organization, mobile operator, telecommunications

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Abstrakt

Tato práce se zabývá měřením tržní síly. Jelikož je tržní síla významným faktorem určujícím povahu konkurenčních vztahů na trhu, její měření je důležitým aspektem zejména politiky ochrany hospodářské soutěže. Práce se zaměřuje na několik různých metod používaných k určení tržní síly. Mezi nejznámější patří Lernerův index a Herfindahlův-Hirschmanův index, které spadají do SCP metod. Další skupinou jsou NEIO modely, které poskytují empirickou analýzu příslušného trhu.

K určení stupně tržní síly jsme vybrali trh českých mobilních operátorů. Použili jsme data tří největších českých operátorů (tj. O2, T-Mobile a Vodafone) z období 2000-2013. Nejprve je využit model Röllera a Parkera (1997) k určení tržní struktury. Poté je aplikován Appelbaumův (1982) model, který určuje tržní sílu za použití dat na úrovni odvětví.

Klíčová slova: tržní síla, tržní struktura, Lernerův index, konkurence, organizace trhů a odvětví, mobilní operátor, telekomunikace

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Declaration of Authorship

I hereby proclaim that I wrote my bachelor thesis on my own under the leadership of my supervisor and that the references include all resources and literature I have used.

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List of Abbreviations

ARPU	Average Revenue per User
CDMA	Code Division Multiple Access
CR	Concentration Ratio
CZK	Czech Koruna
DWL	Deadweight Loss
GDP	Gross Domestic Product
GSM	Global System for Mobile Communications
HHI	Herfindahl-Hirschman Index
LI	Lerner Index
MVNO	Mobile Virtual Network Operator
NEIO	New Empirical Industrial Organization
IPTV	Internet Protocol Television
R&D	Research and Development
SCP	Structure-Conduct-Performance
SIM	Subscriber Identity Module

Introduction

Suppliers and especially manufacturers have market power because they have information about a product or a service that the customer does not and cannot have, and does not need if he can trust the brand. This explains the profitability of brands.

Peter F. Drucker

Perfect competition along with all its assumptions is an unrealistic concept, even though a desirable one. Price-taking behavior, as well as zero degree of market power, is not usually a good approximation of the real world markets. Since firms can conduct collusion, create barriers to entry or differentiate their products, competition is often distorted.[1] Consequently, the need to assess market power (and subsequently competition) emerges in order to maintain competition's appropriate level.

Measuring market power is one of the key aspects of industrial organization. Indirect measures are often employed, such as profitability, market concentration measured by Herfindahl-Hirschman index or by concentration ratio, entry barriers or various measures of monopoly like Lerner index. The issue with this measures is that they can indicate something else than market power. For example, profitability can occur due to a high degree of efficiency insted of market power. High Lerner index, which measures the deviation of price from marginal cost, can simply reflect the need to cover fixed costs and therefore setting price above MC. The biggest advantage of the mentioned measures is that they are relatively easy to compute, moreover the data on market shares, prices or profits are usually well accessible.

Another possibility how to assess market power is by empirical estimation. Many models have been already introduced and are nowadays widely used in practice. The models can be divided into two sections of structural and non-structural measures. Structural measures take a use of the Lerner index by employing some version of it. On the contrary, non-structural measures

[1] In a sense of existence of market power.

estimate market power by relying on comparative statics of a firm.

Four empirical models will be described.[2] Iwata (1974) and Appelbaum (1982) proposed very similar measures of market power using conjectural variations.[3] Moreover, Appelbaum provided additional index for industry-level market power. The model by Panzar and Rosse (1987) belongs to a non-structural approach. It examines the relationship between revenue and prices for inputs, which is assumed to indicate the market power. A nonnegligible advantage of this model are modest requirements concerning data. The last model is from Bresnahan (1982), who used a concept of perceived marginal revenue to identify market power. Using the approach suggested by Shaffer (1983), it will be shown how the indexes from all four models are connected together.

To conduct an empirical analysis of market power, we have chosen the market of czech mobile operators. Since mobile services belong to the ones used every day and by almost everyone, it becomes necessary to maintain an appropriate degree of competition in such a market. We examine the three largest operators - O2, T-Mobile and Vodafone - in a period 2000-2013 using panel data collected mostly from financial statements. The analysis is done in two steps. Firstly, we determine the market structure. This is done by using the model from Parker and Röller (1997).[4] Market conduct is approximated by conjectural elasticity, which has to be estimated. After identifying conduct, we apply Appelbaum's industry-level index to assess market power. In order to compute the index, we have to run additional regression to estimate the elasticity of demand.

Structure of the thesis is as follows: Chapter 1 provides an introduction to market power and a discussion of its possible sources. Several methods

[2]While all the four models employ the assumption of a single homogenous product, Schroeter and Azzam (1990) provided a similar analysis of market power in multi-product markets.

[3]An in-depth analysis of conjectural variation provided Kamien and Schwartz (1983). They determined the relationship between the functional form of demand and conjectural variation. Moreover, they described how are related conjectural variations depending on output and depending on price.

[4]Šopovová (2010) applied the same model on the same market of mobile operators using period 2000-2008. Unfortunatelly, because her analysis did not produce any significant results (not even on conduct parameter), we cannot refer to her conclusions.

of measuring market power are proposed in Chapter 2 containing also the four models described above. The second part of the thesis is dedicated to empirical analysis. Chapter 3 includes information about relevant market of mobile operators, such as historical background and nowadays trends. Finally, Chapter 4 provides empirical model to identify the conduct, index to measure market power, revision of data used and interpretation of all results. The overall summary takes place in Conclusion. In Appendix can be found an additional chapter about market structures, as well as several graphs and tables.

1 Market Power Preliminary

In a perfect competition, price is equal to marginal cost. No firm has an ability to affect market price by changing its own output. If the opposite is true, we say that firm possesses market power.

Market power is the ability of firm to raise price over marginal cost. In a perfectly competitive market, firms have no market power, since price equals marginal cost. Monopoly is an opposite extreme, price is well above marginal cost. Oligopoly yields price between perfectly competitive and monopoly structure, so firms possess some degree of market power, but not as high as monopolist does.

If a firm has market power, it can affect market output by changing a quantity of its own output. If the overall output is affected in the same or opposite direction depends on market's behavioral pattern.

Market power is usually associated with antitrust policy. An industry with a high degree of market power indicates either possible presence of cartel, another type of collusion or even an existence of monopoly. However, as stated in Motta (2009), if regulator detects monopoly, it does not mean that any regulations or remedies should be imposed. There are also laws, such as patent and copyright, that protect monopoly. Welfare gain from monopoly should be compared with its inefficiency, i.e. deadweight loss. Therefore, a high degree of market power is not necessarily an indicator of anything "wrong" in a market. Another possible use of degree of market power is in a case of mergers. When a significant merger takes place, it is convenient to measure market power to assess the effect of merger on competition.

Market power can stem from several sources. It is important to properly go through them to gain better understanding of market power's nature. Knowing sources of market power can help one to assess possible existence of a significant degree of market power.

1.1 Sources of Market Power

Identifying sources of market power can be a tricky task to do. Most of the sources can be market power's consequences as well. Moreover, it is difficult to describe an exact relationship between market power and its particular source. Most of a time we rely on relationships known from practice rather than on empirical estimation of correlation.

Market power generally stems from two main sources: elasticity of demand and barriers to entry.

The elasticity of demand is an important determinant of market power. If a firm faces a demand curve with an infinite elasticity (that is horizontal curve), it has to set its price equal to marginal cost and therefore has no market power. On the contrary, if the elasticity is close to zero (vertical curve), firm can set the price almost freely.

Low elasticity of demand has several causes. When firms produce very different products and none of them has close substitutes, this makes consumers willing to pay higher prices and hence demand is less elastic. Firms put a lot of effort into product differentiation in order to attain market power and excessive profits. Products can be different not only in physical characteristics like shape, color or quality of material used, but also in a place where the product is available. For example, a particular firm does not need to have high degree of market power in industry as a whole, but only to possess market power in a certain area, where other substitutes are not available. This situation gives consumers no choice but to accept even higher prices.

Also consumers' loyalty to certain brand or goodwill have the same outcome as product differentiation.

Barriers to entry is a characteristic, which has a considerable effect on market structure. Generally, if there are no barriers and new firms can enter the industry freely, incumbents have to face the possibility that a new firm can enter the market at any time and attract all (or most of the) customers. Hence, this threat forces firms to maintain lower prices in order to stay competitive. On the other hand, if the barriers to entry are so strong that there cannot be any entrants, and there are only a few incumbents in a market, they will probably dispose of a considerable degree of market power.

"The primary explanation for entry barriers is the existence of entry cost." (Shy 1995) It concerns mainly the sunk costs. Those are "...costs that cannot be reversed or for which the investment associated with paying them cannot be converted to other causes, or resold in order to recapture part of the investment cost." (Shy 1995) Sunk costs include fees, advertising or costs related to plant and equipment. Furthermore, incumbent can artificially rise entry cost, for example by investing more on R&D. Possible entrants then have to invest more too in order to keep up with incumbent regarding production technology.

Some industries are highly regulated, because it is convenient to restrict a number of firms in those markets. As an example can serve an armament industry. The regulation measures, which are imposed to achieve the restriction, create barriers to entry. Also a possession of exlusive rights or some particular resource falls into this category. The entry to the industry is then aggravated, if not impossible.

Barriers created by an incumbent also occur. It concerns setting dumping, or very low, prices. New firm cannot enter then, because the price war would be destructive for the entrant.

Last but not least, a nonnegligible role among sources of market power have economies of scale. In case of existence of increasing economies of scale, well established and large-size incumbent has a significant cost advantage against possible entrants. A decisive impact of such an advantage on new entries is plain.

2 Methods of Measurement

Many methods for estimating market power were introduced during years. Some of them are widely used in antitrust cases, where a degree of market power can be an indicator of unlawful conduct. The main purpose of this chapter is to introduce and discuss some of these methods. We also provide a comparison of particular methods and show some relations between them.

An important question, which should be answered before dealing with particular measures, is: What should exactly be measured? Despite the definition of market power like an ability to deviate price from marginal costs, many methods of measurement take an indirect approach. They are focused basically on sources of market power or its consequences. By analysing of these, one can derive conclusions about market power itself. Discussions have arised concerning appropriateness of the indirect measures, their correlation with market power or their empirical estimation. Some of these aspects are discussed in this chapter as well, the others, such as empirical estimation issues, are considered out of the scope of the thesis.

The most famous method for measuring market power is *Lerner index*. It was proposed by Lerner (1934) and became a base for many other measures. Despite the fact that many questions have arised about its appropriateness, it is still a useful tool for measuring market power. It belongs to *Structure-conduct-performance* (SCP) paradigm. "In the SCP paradigm, ..., measures of structure are used to explain the difference in market performance across industries." (Carlton and Perloff 2000)

Generally, Lerner index can be called a *price-cost margin* measure, because it shows a deviation of price from marginal costs (as a fraction of price).

Another type of measures, which belong to SCP approach, are those concerning market shares. Particularly *concentration ratio* and *Herfindahl-Hirschman index*. The latter one is the one of our interest. It is easy to compute and therefore widely used in practice, e.g. in merger analysis.

Each firm has beliefs (or conjectures) about what the reactions of other firms on changing its output would be. These beliefs are called *conjectural variations*. Conjectural variation models belong to the *New empirical industrial organization* (NEIO) approach. In contrast to SCP paradigm, in NEIO "firms' price-cost margins are not taken to be observables; economic marginal cost (MC) cannot be directly or straightforwardly observed" and "firm and industry conduct are viewed as unknown parameters to be estimated." (Bresnahan 1989) The main advantage of NEIO against SCP is an empirical estimation of a degree of market power. Generally, NEIO provides an econometrical model based on economic theory and using suitable set of data estimates conduct parameters together with price-cost margins. NEIO models involve also the models that take a use of comparative statics of particular firms to assess market power.

2.1 Lerner Index

Let us start by introducing a formula for the Lerner index,

$$LI = \frac{p - MC}{p} \tag{2.1}$$

where p is a firm's price and MC its marginal costs.

Lerner (1934) was the one, who deviated attention from the relationship between price and average costs to price's relationship with marginal costs. He stressed a monopolist's allocative inefficiency rather then monopolist's profit. Moreover, he identified a social optimum as an equilibrium in a perfectly competitive structure. One can therefore argue that LI rather than market power measures a deviation from this social optimum reached in a perfect competition.

Other potential pitfall, according to Elzinga and Mills (2011), rises from the notion that setting price over marginal costs can reflect something else than the exercise of market power. The need to cover fixed costs is a sufficient example. Then a firm's rise of price cannot be attributable to its dominant position in a market, but rather to adverse circumstances.

As Elzinga and Mills have pointed out, LI is a static index and does not take into account dynamic effects such as technological changes or innovation. Furthermore, it is focused only on price control of a monopolist rather than possible issues stemming from non-pricing area.

Because one has to know a firm's demand curve and marginal costs to compute the Lerner index, this measure became impractical in this respect.

Since there exist arguments like those mentioned in paragraphs above, the use of the index in practice is very limited. There were some attempts to make use of LI in antitrust cases, but because of doubts about what Lerner index exactly measures, it has been more or less replaced by more rigorous models. Despite the fact it is not used in practice, LI still plays a nonnegligible role in industrial organization theory.

One example of the use of LI in theory is a derivation of a welfare loss in a presence of monopoly as shown in Pepall *et al.* (2008). As is well known, welfare loss in the monopoly case equals deadweight loss (DWL). It is a triangle, which one side is the difference between a monopolist's price P^M and a perfectly competitive price P^C. The other side is the difference between an output produced by a perfectly competitive firm Q^C and a lower output Q^M produced by monopolist. We can write the DWL as

$$DWL = \frac{1}{2}(P^M - P^C)(Q^C - Q^M) \tag{2.2}$$

It appears convenient to measure the DWL as a fraction of revenue.Using the fact that $P^C = MC$, (2.2) then becomes

$$\frac{DWL}{P^M Q^M} = \frac{1}{2}\frac{P^M - MC}{P^M}\frac{Q^C - Q^M}{Q^M} \tag{2.3}$$

We now employ the elasticity of demand. It indicates how the output will increase, if price falls. In our case, if price is about to fall to the competitive level MC, output will then rise to the competitive level Q^C. Elasticity can be written as

$$e = \frac{\frac{Q^C - Q^M}{Q^M}}{\frac{P^M - MC}{P^M}} \tag{2.4}$$

Clearly,

$$\frac{Q^C - Q^M}{Q^M} = e\frac{P^M - MC}{P^M} \tag{2.5}$$

and

$$\frac{DWL}{P^M Q^M} = \frac{1}{2} eLI^2 \tag{2.6}$$

$$= \frac{1}{2} LI \tag{2.7}$$

Hence, the welfare loss caused by monopoly is a one half of the Lerner index. It is usefull to address a question about loss in welfare. If the loss caused by monopoly is not severe, maybe it would not be worth for antitrust authorities to deal with it.

Other use of Lerner index can be seen further in the chapter.

2.2 Herfindahl-Hirschman Index

Despite the fact that Herfindahl-Hirschman index (HHI) is frequently used as a measure of market power, its interpretation like that is questionable. The index is in a form

$$HHI = \sum_{i=1}^{n} S_i^2$$

where S_i is a market share (as percentage) of the i^{th} firm and n is a number of firms in an industry. Obviously, the index does not fulfill the definition of market power, therefore is not a direct measure of it. However, as stated in Rhoades (1993), high HHI indicates a few firms having large market shares and this rises the probability of distorted competition and consequently high degree of market power.[5]

If we consider the relationship between market share and profitability, where profitability is assumed to be a suitable proxy for market power, we cannot exactly define their connection. Clarke *et al.* (1984) have examined the relationship between market concentration and profitability. Generally, concentration and profitability were assumed to be positively correlated. But high profits can stem from greater efficiency rather than from higher market share. As Clarke *et al.* have shown, it is incorrect to put overemphasis to high concentration.

[5]Suppose other things being equal.

Saving (1970) has derived a connection between concentration ratio[6] and Lerner index. Let us assume a market with n firms, the largest k of which form a cartel. Other $n-k$ firms are supposed to be price takers. The market demand function is

$$Q_M^D = f(p) \tag{2.8}$$

and the supply function of price takers is stated as

$$Q_{n-k}^S = g(p) \tag{2.9}$$

Assuming a clearing market condition is fulfilled, we can write the demand of k firms

$$Q_k^D = f(p) - g(p) \tag{2.10}$$

We derive an elasticity of demand, f and g being continuously differentiable

$$\frac{\frac{dQ_k^D}{Q_k^D}}{\frac{dp}{p}} = \frac{df(p)}{dp}\frac{p}{Q_k^D} - \frac{dg(p)}{dp}\frac{p}{Q_k^D} \tag{2.11}$$

$$= \frac{f(p)}{Q_k^D}\frac{\frac{df(p)}{f(p)}}{\frac{dp}{p}} - \frac{g(p)}{Q_k^D}\frac{\frac{dg(p)}{g(p)}}{\frac{dp}{p}} \tag{2.12}$$

$$\eta_k = \frac{f(p)}{Q_k^D}\eta_M - \frac{g(p)}{Q_k^D}\epsilon_{n-k} \tag{2.13}$$

where η_M and ϵ_{n-k} are elasticity of market demand and elasticity of supply of $n-k$ firms, respectively. Knowing

$$L_k = \frac{p - MC}{p} = -\frac{1}{\eta_k} \tag{2.14}$$

we can substitute for η_k

$$L_k = -\frac{1}{\frac{f(p)}{Q_k^D}\eta_M - \frac{g(p)}{Q_k^D}\epsilon_{n-k}} \tag{2.15}$$

Obviously $\frac{f(p)}{Q_k^D} = \frac{1}{S_k}$ and

$$\frac{g(p)}{Q_k^D} = \frac{f(p) - Q_k^D}{Q_k^D} \tag{2.16}$$

$$= \frac{1 - S_k}{S_k} \tag{2.17}$$

[6]Concentration ratio is defined as

$$CR_m = \sum_{i=1}^{m} S_i$$

Therefore,

$$L_k = -\frac{S_k}{\eta_M + (S_k - 1)\epsilon_{n-k}} \tag{2.18}$$

According to (2.18), Lerner index of the k largest firms is a function of their joint market share, market elasticity of demand and supply elasticity of price takers. Consequently, despite the fact that market share is connected to the Lerner index (at least in the cartel model proposed by Saving), it is misleading to rely only on this connection. Particularly if we do not know η_M and ϵ_{n-k}.

2.3 NEIO Models

There are various models used for market power estimation. The four models presented in this section are by Iwata (1974), Appelbaum (1982), Bresnahan (1982) and Panzar and Rosse (1987), respectively. They were chosen because of their frequent application in practice and because they are considered as one of the basic models for measuring market power. The first two models employ conjectural variations to derive some version of the Lerner index, which is then estimated. Bresnahan's approach is based on a concept of perceived marginal revenue. Panzar and Rosse's model uses an estimated relationship between revenues and prices for inputs as a proxy for market power.

The models presented in this section are only microeconomic ones. Relevant econometric models as well as issues related to them are not considered.

The first is a model proposed by Iwata (1974). Let us assume an oligopolistic market, where all firms produce a homogenous product. Let p be market price and Q market output quantity. Then

$$p = f(Q) \tag{2.19}$$

is the market inverse demand function. Moreover, in equilibrium supply quantity $Q_s = q_{s1} + \ldots + q_{sn}$ equals demand quantity $Q_d = q_{d1} + \ldots + q_{dn}$. Profit maximization can be written as

$$\pi_i = TR_i - TC_i \tag{2.20}$$

TR_i and TC_i are total revenues and total costs, respectively. Marginal revenue is then

$$\begin{aligned} MR_i &= p + \frac{dp}{dq_i} q_i \\ &= p + \frac{dp}{dQ}\frac{dQ}{dq_i} q_i \\ &= p + \frac{dp}{dQ}(1 + \frac{d(\sum_{k\neq i} q_k)}{dq_i}) q_i \end{aligned} \tag{2.21}$$

Defining $\theta_i = \frac{d(\sum_{k\neq i} q_k)}{dq_i}$, we can call θ_i the conjectural variation of the i^{th} firm.[7]

The first order condition is

$$p + \frac{dp}{dQ}(1 + \theta_i) q_i - MC_i = 0 \tag{2.22}$$

and second order condition

$$\frac{dp}{dq_i} + \frac{dp}{dQdq_i} q_i + \frac{dp}{dQ} + \frac{dp}{dQdq_i} q_i \theta_i + \frac{dp}{dQ}\theta_i + \frac{dp}{dQ}\frac{d\theta_i}{dq_i} q_i - \frac{dMC_i}{dq_i} < 0 \tag{2.23}$$

After some rearrangements and using

$$\frac{dp}{dq_i} = \frac{dp}{dQ}(1 + \theta_i)$$

(2.23) can be rewritten as

$$(2 + 2\theta_i + \frac{d\theta_i}{dq_i} q_i)\frac{dp}{dQ} + \frac{d^2 p}{dQ^2}(1 + \theta_i)^2 q_i - \frac{dMC_i}{dq_i} < 0 \tag{2.24}$$

If ϵ is the inverse of price elasticity of demand (i.e. $\epsilon = \frac{dp}{dQ}\frac{Q}{p}$), (2.22) becomes

$$p + \epsilon \frac{p}{Q}(1 + \theta_i) q_i - MC_i = 0 \tag{2.25}$$

From this adjusted first order condition, we can get market share equation

$$\frac{q_i}{Q} = \frac{1}{\epsilon p}\frac{MC_i - p}{1 + \theta_i} \tag{2.26}$$

Summing over i gives

$$\frac{\sum_{i=1}^{n} q_i}{Q} = \frac{1}{\epsilon p}\sum_{i=1}^{n}\frac{MC_i - p}{1 + \theta_i} \tag{2.27}$$

$$1 = \frac{1}{\epsilon p}\sum_{i=1}^{n}\frac{MC_i}{1 + \theta_i} - \frac{1}{\epsilon}\sum_{i=1}^{n}\frac{1}{1 + \theta_i} \tag{2.28}$$

[7] In some papers or textbooks, conjectural variation is considered to be $\frac{dQ}{dq_i}$, i.e. the change in overall market output caused by a change in q_i. But it is only the matter of notation and it changes nothing on the conducted analysis.

If we express p from (2.28)

$$p = (\frac{1}{\epsilon}\sum_{i=1}^{n}\frac{MC_i}{1+\theta_i})/(1+\frac{1}{\epsilon}\sum_{i=1}^{n}\frac{1}{1+\theta_i}) \tag{2.29}$$

we can see it is a function of three factors - marginal cost MC_i, conjectural variation θ_i and price elasticity of demand $e = \frac{1}{\epsilon}$. Hence, we have shown that conjectural variation affects a deviation of price from marginal costs.

We can directly derive conjectural variation from (2.25)

$$\theta_i = \frac{Q}{q_i}\frac{MC_i - p}{p}e - 1 \tag{2.30}$$

Note that $\frac{MC_i - p}{p} = -LI$, where LI is the Lerner index. Because we do not know a firm's marginal cost or price elasticity of demand, empirical estimation has to be used to obtain these. As will be shown in the chapter concerning estimation of market power on the czech market of mobile operators, this can be done by estimating demand and cost equations.

Similar approach used Appelbaum (1982). He employed *conjectural elasticity* instead of variation to obtain a measurement of oligopoly power. His model is applicable to more general oligopolistic markets than Iwata's model and particular conditions are introduced to apply the model on an aggregate industry data.

Consider an industry with n firms producing homogenous product and using k inputs $x = (x_1 + \ldots + x_k)$. The cost function of the i^{th} firm is $C_i = C_i(q_i, w)$, where q_i is firm's output and w is a price of the inputs. We assume that all firms are facing the same input prices.

The market demand curve is defined by

$$Q = f(p, z) \tag{2.31}$$

where Q is market output, p is market price and z contains exogenous factors, such as prices of substitutes. Demand function f is decreasing in p.

Using the Shephard's lemma, we get a conditional input demand of the i^{th} firm as

$$x_i = \frac{\delta C_i(q_i, w)}{\delta w} \tag{2.32}$$

Moreover, profit maximization can be expressed as

$$\max_{q_i} \pi_i = pq_i - C_i(q_i, w) \tag{2.33}$$

The first order condition is then

$$p + \frac{dp}{dq_i}q_i - \frac{\delta C_i(q_i, w)}{\delta q_i} = 0 \tag{2.34}$$

After adding $\frac{dQ}{dQ}$, $\frac{p}{p}$ and $\frac{Q}{Q}$ to (2.34), we obtain

$$p + \frac{dp}{dQ}\frac{Q}{p}.\frac{dQ}{dq_i}\frac{q_i}{Q}.p = MC_i \tag{2.35}$$

$$p(1 + \gamma_i \epsilon) = MC_i \tag{2.36}$$

γ_i is conjectural elasticity $\frac{dQ}{dq_i}\frac{q_i}{Q}$ and ϵ is an inverse of price elasticity of demand $\frac{dp}{dQ}\frac{Q}{p}$. If we focus on the conjectural elasticity, it is obvious that it is composed from conjectural variation and market share. Therefore, we can rewrite it as

$$\gamma_i = (1 + \theta_i)S_i \tag{2.37}$$

where θ_i is conjectural variation from the previous model and S_i is a market share. If we have Cournot oligopolists, then $\gamma_i = S_i$ ($\theta_i = 0$). In a case of perfect competition, $\gamma_i = 0$ ($\theta_i = -1$). Existence of a monopoly yields $\gamma_i = 1$ ($\theta_i = 0$ and $S_i = 1$).

Knowing (2.36) we can obtain a measure of oligopoly power as

$$\ell_i = \frac{p - MC_i}{p} = -\gamma_i \epsilon \tag{2.38}$$

It is obvious that ℓ_i is the Lerner index, which equals conjectural variation times negative inverse of the elasticity of demand. Because both p and MC_i are positive and $p \geq MC_i$, then $\ell_i \geq 0$ and, because of non-negativity of MC_i, $\ell_i \leq 1$. Thus $\ell_i \in [0, 1]$.

If we substitute (2.37) for γ_i and rearrange

$$\frac{p - MC_i}{p} = -(1 + \theta_i)S_i \epsilon \tag{2.39}$$

$$\theta_i = \frac{Q}{q_i}\frac{MC_i - p}{p}e - 1 \tag{2.40}$$

we obtain the same equation as (2.30) in Iwata's model. Hence, it does not matter, if one starts with conjectural variation or conjectural elasticity, both lead to the same conclusion and the same measure of the degree of market power.

The ℓ_i defined above is a measure for a firm-level market power. If we want to know the degree of market power fot the whole industry, we just have to sum ℓ_i over i

$$\mathcal{L} = \sum_{i=1}^{n} \ell_i S_i \tag{2.41}$$

Adding market share $S_i = \frac{q_i}{Q}$ is often used. Then $\mathcal{L}$ becomes "a weighted average of the firm measure", alternatively, "it is the ratio of the sum of non-competitive rents in the industry and total industry revenues" (Appelbaum 1982).

(2.41) can be adjusted as follows

$$\mathcal{L} = \sum_{i=1}^{n} (-\gamma_i \epsilon) S_i \tag{2.42}$$

$$= -\epsilon \sum_{i=1}^{n} (1 + \theta_i) S_i^2 \tag{2.43}$$

where $\sum_{i=1}^{n} S_i^2$ is the Herfindahl-Hirschman index. So the HHI is a special case of the measure $\mathcal{L}$.

To sum up, we have shown that the measure proposed by Appelbaum is directly connected to those used by Iwata. Furthermore, it is connected to Herfindahl-Hirschman index as well as Lerner index.

So far, previous models employ some kind of Lerner index to obtain a measure of market power. There are also *non-structural measures*, which do not take a use of the Lerner index (or Herfindahl-Hirschman index). The first one to be mentioned is the approach used by Bresnahan (1982). He used *perceived marginal revenue* (MR_p) and the fact that each firm maximizes its profit by $MC = MR_p$. $MR_p = P$ predicts a perfectly competitive setting, $MR_p = MR$ indicates monopoly (or joint cartel) and $MR_p < P$ means the oligopoly behavior. Demand function has its typical form,

$$Q = f(P, z_1) \tag{2.44}$$

where z_1 are exogenous factors affecting demand. According to Bresnahan, the first order condition for profit maximization is

$$P + \lambda h(Q, z_1) = MC(Q, z_2) \tag{2.45}$$

i.e. perceived marginal revenue $P + \lambda h(Q, z_1)$ equals marginal cost. Analogously to z_1, z_2 are exogenous variables in the cost equation. λ is considered to be a measure of market power. If $\lambda = 0$, marginal cost will equal price. $\lambda = 1$ is a case of monopoly. Number between 0 and 1 indicates some kind of oligopoly setting, e.g. $\lambda = \frac{1}{n}$ corresponds with Cournot oligopolists. Bresnahan has also shown that (2.45) is econometrically identified.

Bresnahan's approach was important to mention, because similar equation as (2.45) can be seen in the last chapter concerning empirical estimation of market power. In that case, λ is a conjectural elasticity and function h is a semi-elasticity of inverse demand. The equation $\lambda = \gamma$ is going to be justified at the end of this chapter.

Different approach than Bresnahan described Panzar and Rosse (1987) by using a reduced form revenue function. Assume a monopolist, whose reduced form revenue function is decreasing as vector of input prices increases. Suppose a revenue function $R(q, z)$, where z is a vector of exogenous factors affecting revenue, and a cost function $C(q, w, t)$, w being a vector of input prices and t exogenous factors affecting costs. Denote

$$q^0 = argmax_q\{\pi(q, z, w, t)\} \tag{2.46}$$

$$q^1 = argmax_q\{\pi(q, z, (1 + h)w, t)\} \tag{2.47}$$

and

$$R^0 = R^*(z, w, t) \tag{2.48}$$

$$R^1 = R^*(z, (1 + h)w, t) \tag{2.49}$$

where h is a scalar. Knowing that cost function is linearly homogenous in w, we can write

$$R^1 - (1 + h)C(q^1, w, t) \geq R^0 - (1 + h)C(q^0, w, t) \tag{2.50}$$

Similarly,

$$R^0 - C(q^0, w, t) \geq R^1 - C(q^1, w, t) \tag{2.51}$$

Multiplying (2.51) by $(1 + h)$ and summing with (2.50) gives

$$h(R^0 - R^1) \geq 0 \tag{2.52}$$

Dividing (2.52) by $-h^2$ results in

$$\frac{R^*(z, (1 + h)w, t) - R^*(z, w, t)}{h} \leq 0 \tag{2.53}$$

Finally, taking the limit of (2.53) as $h \to 0$ and dividing by R^* produce

$$H = \sum \frac{\frac{\partial R^*}{R^*}}{\frac{\partial w_i}{w_i}} \leq 0 \tag{2.54}$$

H is a measure of monopoly equilibrium. In the same fashion, Panzar and Rosse (1987) have shown that $H \leq 1$ for a monopolistic market, $H = 1$ for a perfect competition and $H \geq 0$ for oligopolists.

This non-structural measure is widely used in empirical studies, especially in those examining banking industry. Its biggest advantage are the modest data requirements. One does not need to know neither firm's cost function nor price function. Some of the studies employ the models, in which a dependent variable is not a reduced form revenue function, but a price function instead. Also it is commonly used to have a control variable for a firm's scale. But, according to Shaffer *et al.* (2012), one has to be cautious about using a firm's scale or price as a dependent variable. One of their findings is that "a price equation and scaled revenue function, ..., cannot identify imperfect competition in the same way that an unscaled revenue function can." (Shaffer *et al.* 2012)

Lastly, it can be shown that three of the models introduced in this chapter are directly connected - Iwata's, Bresnahan's and Panzar and Rosse's ones. The method was proposed by Shaffer (1983). The purpose is to prove the relation between Iwata's (and Appelbaum's as well) conjectural elasticity, Bresnahan's λ and H statistic from P-R model. We start by denoting $p = \frac{R}{q}$

and writing the elasticity as

$$e = \frac{R}{q^2}\frac{dq}{d(\frac{R}{q})} \tag{2.55}$$

Let us write

$$e = (\frac{Rd(q)}{q^2} + \frac{d(R)}{q} - \frac{d(R)}{q})\frac{1}{d(\frac{R}{q})} \tag{2.56}$$

$$= \frac{d(R)}{qd(\frac{R}{q})} - 1 \tag{2.57}$$

$$\frac{e+1}{e} = q\frac{d(R)}{d(q)}\frac{1}{R} \tag{2.58}$$

The first order condition is

$$\frac{d\pi}{dq} = \frac{R}{q}\frac{(e+1)}{e} - MC \tag{2.59}$$

Assuming constant marginal cost and constant elasticity of demand, the second order condition is then

$$\pi_{qq} = \frac{d\pi^2}{d^2q} = \frac{R(e+1)^2}{q^2e^2} - \frac{R(e+1)}{q^2e} \tag{2.60}$$

Putting (2.60) together with Panzar and Rosse's $H = \frac{(d\frac{R}{q})^2}{R\pi_{qq}}$ produces

$$H = \frac{R(e+1)^2}{R(e+1)^2 - eR(e+1)} \tag{2.61}$$

$$= e + 1 \tag{2.62}$$

If E is an elasticity of market demand and γ a conjectural elasticity, clearly

$$E = e\gamma = (H-1)\gamma \tag{2.63}$$

$$\gamma = \frac{E}{H-1} \tag{2.64}$$

Hence, we have shown the connection between conjectural elasticity γ and H statistic. Now we prove their relationship with Bresnahan's λ. In a monopoly,

$$MR = p(1 + \frac{1}{E}) \tag{2.65}$$

and from Bresnahan (1982)

$$h = MR - p = \frac{p}{E} \tag{2.66}$$

Therefore, $MR_p = p + \lambda \frac{p}{E}$, but in general $MR_p = p(1 + \frac{1}{e})$. It results in

$$\lambda = \gamma \tag{2.67}$$

$$\lambda = \frac{E}{H - 1} \tag{2.68}$$

To sum up, we have shown that all three indicators of market power (γ, H, λ) are mutually dependent. Equation (2.67) even proves an equality of the two of them.

In this chapter, two main streams of measurement were introduced: SCP paradigm and NEIO approach. Whereas we have been focused on a theory behind market power until now, next two chapters are concerning an empirical estimation of market power. Chapter 3 describes the czech market of mobile operators, which is the one of examination. Chapter 4 then provides an empirical model, revision of data used and interpretation of results.

3 Czech Market of Mobile Operators

In the previous section, several methods for measuring market power have been discussed, but only theoretically. From now on, we focus on empirical estimation.

For the purpose of estimation of market power, we have chosen the market of mobile operators. Almost every person is a mobile market participant. Nowadays, in the Czech Republic there are even more active SIM cards than citizens. Because mobile services is something widely used by (almost) everyone, it is in a common interest to maintain a reasonable degree of competition in the market.

In this chapter, several information about the czech mobile operators are provided to equip the reader with a basic overview about the market. Not all of the mentioned operators are involved in the empirical analysis, because of either negligible market share or accessibility of data.

In the czech market, there operate four mobile operators - O2, T-Mobile, Vodafone and U:fon. Since U:fon uses a different type of network, as will be mentioned further, it has a considerable market disadvantage. Because it posseses a negligible market share, it is dropped from the empirical analysis. To obtain an overall overview about czech mobile operators, U:fon is described in this chapter too.

More and more important role in the market play the virtual operators. Despite the fact that most of them started to operate not long ago, they managed to attract a nonnegligible part of customers. Because of bad accessibility of data about virtual operators, they are all dropped from the empirical analysis as well.

3.1 O2 Czech Republic

The story of O2 began in 1990, when Eurotel entered the czech market as the first mobile operator. Until 1996 Eurotel was the only operator on the czech market. Because the market was in its beginning, Eurotel's services were expensive and available only for a small fraction of population. Eurotel's major share was held by SPT Telecom, renamed to Czech Telecom in 2000. In 2006 a merger between Eurotel and Czech Telecom took place and the name was changed to Telefónica O2 Czech Republic. After 7 years, in 2013 Telefónica has changed its owner - Telefónica Czech Republic was sold to Petr Kellner's investment group PPF. More precisely, PPF bought 66% share of czech Telefónica. Parent company, Telefónica S.A., has kept 4,9% share. Year after the transaction, the general meeting has decided to change the name to O2 Czech Republic.

O2 was the first operator, which has started to provide services of the third generation mobile network (3G). It was also the first one in introducing so popular unlimited tariffs. Those tariffs (called FREE in O2) started a revolution in mobile services - nowadays many tariffs offer something "unlimited". Another primacy relates to opening O2's network to virtual operators.

With regard to mobile services, O2 falls short of T-Mobile. But considering O2 as a whole, it is an apparent winner. O2 offers, besides mobile services, a large scale of fixed lines services, cloud and hosting services, and is the largest provider of (IPTV) in the Czech Republic.

3.2 T-Mobile

Regarding to the number of active SIM cards, the absolute winner is T-Mobile, which has been occupying the first place since 2005. It entered the czech market in 1996 as Paegas, which was owned by RadioMobil. In contrast to Eurotel, Paegas started to operated in a digital system GSM. Its services were targeted to a broader public by maintaining lower prices and therefore became more accessible to the czech population. In 2002, Paegas has changed its name to T-Mobile after selling the majority interest to the Deutsche Telekom. The last change took place in 2014, when Deutsche Telekom bought the minority interest too and became a 100% owner of the T-Mobile Czech Republic.

T-Mobile is, as well as O2, an integrated operator, which offers a variety of services concerning fixed line telecommunications and IT services or system integration consulting. According to the magazine World Finance, among other awards, T-Mobile Czech Republic is the Best Wireless Telecoms Provider in Eastern Europe.

3.3 Vodafone

The first dual mobile network started to run the third czech mobile operator, Oskar, in 2000. It was the fastest developing operator and therefore managed to catch up with its two competitors in a short time. Oskar's strategy was clear from the start - to become an "operator for customers" and available for as many people as possible. The same idea preserved Vodafone, which has acquired Oskar in 2005. 2009 was the year of openning 3G network for commerce usage. In 2013, Vodafone came up with its own unlimited tariffs, called RED.

Vodafone is the second largest operator in the world, operating in 28 countries. Competitors in the czech market definitely should not underestimate this third entrant, since it has a lot to offer. Its popularity among customers rises thanks to funny advertisements, marketing and promo actions. Vodafone is considered to be the most "friendly" operator out of the three largest.

3.4 U:fon and Virtual Operators

U:fon is the fourth mobile network run by mobile operator Air Telecom. Unlike previous three mobile operators, whose networks are of a type GSM, Air Telecom's network is of a type CDMA. The fundamental difference is that the vast majority of mobile phones are not compatible with a CDMA network. Air Telecom sells special mobile phones, which are, unfortunatelly, poorly equipped. Because of this disadvantage, the number of customers (or active SIM cards) of Air Telecom is incomparable with those of O2, T-Mobile and Vodafone.

U:fon obtained a mobile license in 2007. In 2010, U:fon was bought by MobilKom, which was owned by Penta Investments. MobilKom got to insolvency in 2012 and U:fon was selled to Air Telecom. The original plan was to build a wide scale of branch offices all over the Czech Republic. Air Telecom has then decided to be a low-cost establishment and nowadays there are only a few stores in Prague. In other cities, customers can buy U:fon's products in stores of other mobile operators.

CDMA network is a considerable disadvantage against remaining three operators, the fact that Air Telecom realized in 2013. The negotiation with T-Mobile begun and after a few months, in April 2013, Air Telecom started to operate in T-Mobile's GSM network as a *mobile virtual network operator* (MVNO).

Virtual operators is a phenomenon that started in 2013. Precisely, the first virtual operator was BLESKmobil, which started to operate in 2012. But BLESKmobil is of a type brand reseller, i.e. it does not have its own products, it only resells the products of one of already existing mobile operators. The first adequate virtual operator, with its own products, was the already mentioned Air Telecom. Since it is also the regular mobile operator, it is often not considered as a virtual operator. Usually, the first regular virtual operator is considered Tesco Mobile, which uses an O2's network.

Nowadays, in the Czech Republic operate over 80 virtual operators and at the end of year 2014 they had jointly about 1,2 million active SIM cards. Their popularity is on the increase. Customers believe that the presence of MVNOs can stimulate compatition and consequently push down prices. Unfortunatelly, this effect is still not observable.

4 Estimation of Market Power

Some theoretical models for measuring market power are provided in Chapter 2. Chapter 3 gives a description of the czech market of mobile operators. This chapter is focused on empirical estimation using panel data from period 2000-2013 for the three largest operators in the market. The fourth operator, as well as virtual operators, is excluded from the empirical analysis, since the availability of the data is insufficient. Moreover, the three largest operators possess the vast majority of the market and therefore are of the concern.

First of all, an empirical model for measuring firms' conduct is described and the relevant assumptions are discussed. It is essential to determine the conduct before making conclusions about market power. Furthermore, sometimes knowing the conduct (and therefore market structure) is sufficient for predicting market power, e.g. in case of perfectly competitive market, firms possess no market power.

Secondly, we revise the data used for estimation of both conduct and market power. Then the results of conduct estimation are explained and interpreted. Finally, based on conclusions from conduct estimation, we measure the degree of market power.

4.1 Empirical Model of Conduct

To estimate the degree of market power, we need to know the firms' conduct. The conjectural elasticity serves well enough to determine particular market structure and consequently a behavior pattern of market's participants. We use a model from Parker and Röller (1997) to determine the conduct, since they have examined mobile operators' market as well. But unlike U.S. market, ours has different specifics and therefore some assumptions are adjusted to suit the czech market properly.

Let us assume three symmetric firms producing homogenous product.

Inverse demand function is of the following form

$$p_{it} = f(q_{it}, Z_{it}) \qquad i = 1, 2, 3 \quad \text{and} \quad t = 1, \ldots, 14 \tag{4.1}$$

As usual, q denotes firm's output, Z exogenous characteristics that influence price, such as market population, i is a firm's subscript and t stands for time. Each firm's cost describes the function

$$C_{it} = F_{it} + VC(q_{it}, w_t) \tag{4.2}$$

with F as fixed costs, VC as variable costs and w the prices for inputs.

Implementing the first order condition and after some rearrangements, we obtain the equation containing conjectural elasticity γ_i as in (2.36)

$$p_{it}(1 + \gamma\epsilon_{it}) = MC_{it} \tag{4.3}$$

We can write

$$p_{it}(1 + \frac{\frac{dp_{it}}{p_{it}}}{\frac{dq_{it}}{q_{it}}}\gamma) = MC_{it} \tag{4.4}$$

$$p_{it} - MC_{it} + (\frac{dp_{it}}{dq_{it}}q_{it})\gamma = 0 \tag{4.5}$$

where $\frac{dp_{it}}{dq_{it}}q_{it}$ is semi-elasticity of inverse demand.

The main equation of interest is (4.5). Because p and MC are endogenous, we need also the equations (4.1) and (4.2) in the empirical model. After considering factors that affect price and marginal cost, the model to estimate is

$$p_{it} = a_0 + a_1 log(Q_{it}) + otherfactors + \epsilon_{it} \tag{4.6}$$

$$MC_{it} = b_0 + b_1 Q_{it} + b_2 wage_{it} + b_3 energy_{it} + b_4 repo_t + \nu_{it} \tag{4.7}$$

$$0 = a_1\gamma + c_1 p_{it} - c_2 MC_{it} + \mu_{it} \tag{4.8}$$

where ϵ_{it}, ν_{it} and μ_{it} are independently and identically distributed disturbances, and γ is a conduct parameter to estimate. $Otherfactors$ in (4.6) contains czech population, expenditure for final consumption by households, unemployment rate and a time trend (all except unemployment and trend in logarithm).

Since the model is a system of equations, one of which is non-linear, the suitable estimation method is non-linear three-stage least squares (3SLS).

4.2 Revision of Data

Panel data were collected from financial statements included in annual reports of each operator, from reports of the Czech Telecommunication Office, the Czech Statistical Office and from the Czech National Bank. The chosen period 2000-2013 was selected only due to the accessibility of data.

Despite the effort to collect the data as precisely as possible, some of them had not been found and therefore had to be replaced by sample averages. However, we believe that these adjustments do not affect the estimation in a significant way.

Description of variables used for estimating conduct and market power provides Table 1. Price was computed as twelve times ARPU, i.e. average (monthly) revenue per user. Number of active SIM cards has been taken as operator's output. Population is the czech population in millions and consumption represents final consumption expenditure by households (in millions). Unemployment rate is a percentage. Marginal cost has been approximated by average variable cost. Costs for wages, energy and services are in millions, as well as marginal cost. Repo rate is the Czech National Bank's main monetary policy instrument and is documented as percentage. GDP is that reported by the Czech Statistical Office, production method for its computation has been used. All data, except population, time trend and percentages, are in CZK. Summary of data (minimum, mean and maximum) can be seen in Table 4.

Figures 2 and 3 show a developement of price and output over time. Number of active SIM cards (output) is steadily increasing. This implies the growing need of mobile services. Nowadays, there are even more active SIM cards than number of citizens. On the other hand, price is steadily decreasing. This can be explained by either decreasing marginal cost or growing degree of competition. Operators offer more and more tempting tariffs, with extra sales and bonuses, and therefore the need to maintain current customers is more emergent. Figure 5 shows the curve of market demand. The curve is only approximate, because it is constructed from

Variable	Description
p	Price
Q	Firm's output, number of active SIM cards
pop	Czech population, in millions
$cons$	Final consumption expenditure by households, in millions
$unemp$	Unemployment rate, percentage
$trend$	Time trend
MC	Marginal cost, in millions
$wage$	Cost for wages, in millions
$energy$	Cost for energy, in millions
$serv$	Cost for services, in millions
$repo$	Repo rate set by Czech National Bank, percentage
GDP	Gross domestic product (production method), in millions

Table 1: Description of variables

linear fitted values, which do not need to correspond with real situation on the market. At least we can see that the predicted demand has expected sign - price decreases with increasing output.

4.3 Conduct Estimation Results

Results of estimation of a system (4.6), (4.7) and (4.8) provides Table 2.

There are two insignificant estimates in price equation. Intercept does not have any practical interpretation and so its insignificance is not of much concern. Unemployment rate does not even have the expected sign - one would expect that as unemployment gets higher, people would spend less money because of job uncertainty. So the estimate should be negative. Its insignificance does not make any harm. All other variables in price equation are statistically significant at 1 % level. Estimate of ouput tells us that price will decrease by about -10,49 CZK, if ouput is one percent higher. The same goes for population. 1 % increase causes -581,25 CZK fall in price. It corresponds to the Figure 3 - price decreases as time passes, while population

	Estimate	t-statistic
Price		
Intercept	-51 680,59	-1,23
$log(Q)$	-1 048,91	-5,44
$log(pop)$	-58 125,13	-4,92
$log(cons)$	14 835,42	6,08
unemp	105,31	1,34
trend	-531,18	-5,25
Marginal cost		
Intercept	1 574,32	6,25
Q	-0,00029	-5,43
wage	0,4	5,87
energy	-0,024	-0,14
repo	200,95	4,21
Conduct		
γ	0,29996	3,28
Test for $\gamma = \frac{1}{3}$	...	-0,33

Table 2: Conduct estimation results

gets larger over time. On the other hand, increased consumption expenditure by households implies 148,35 CZK increase in price. If household spends more money, it will probably spend more on telecommunications too. Lastly, time trend captures the effect of time on price. Negative sign of the estimate just corresponds to the Figure 3.

Marginal cost equation has one insignificant variable and that is cost for energy. The sign does not seem right too. All other variables have meaningful interpretation. Intercept is the level of marginal cost, when other variables are set to zero. Well, set output to zero means that a firm does not produce anything, therefore does not have wage or energy costs. Zero repo rate is imaginable, because its actual level is at 0,05 %. Estimate of output has negative sign, which implies a particular economic characteristic

- economies of scale. This gives well-established firms a considerable cost advantage. Economies of scale also usually act like an entry barrier, which can be a possible source of market power. Wage cost causes an increase in marginal cost, as expected. Repo rate affects banks' interest rate. The higher repo rate, the more expensive to take a loan. Thus, repo rate raises costs and marginal costs as well.

Finally, we come to a parameter of our interest, γ. The estimate is around 0,29996 and using a t-test we cannot reject a hypothesis of $\gamma = \frac{1}{3}$. What does it mean? Let us recall equation (2.37)

$$\gamma_i = (1 + \theta_i)S_i \tag{4.9}$$

Assuming Cournot oligopolists, $\theta_i = 0$ and $S_i = \frac{1}{n}$. In our case of three firms,

$$\gamma = \frac{1}{n} = \frac{1}{3} \tag{4.10}$$

Thus, the estimate of γ statistically equal to $\frac{1}{3}$ is consistent with Cournot behavior. If we take a look at Figure 4, the market shares are approximately converging to 33 %. Therefore, the assumption about $\gamma = S_i = \frac{1}{3}$ is not misleading.

4.4 Market Power of Mobile Operators

After estimating the average conduct, we came to a conclusion that behavior of czech mobile operators is consistent with Cournot oligopolists.

To estimate a degree of market power, we use Appelbaum's index

$$\mathcal{L} = -\epsilon \sum_{i=1}^{3} (1 + \theta_i) S_i^2 \tag{4.11}$$

derived in Chapter 2. Since we know that the mobile operators are Cournot competitors, we can write

$$\mathcal{L} = -\epsilon \sum_{i=1}^{3} S_i^2 \tag{4.12}$$

$$= -\epsilon HHI \tag{4.13}$$

Year	$\mathcal{L}$
2000	0,61
2001	0,56
2002	0,54
2003	0,53
2004	0,52
2005	0,5
2006	0,5
2007	0,495
2008	0,49
2009	0,489
2010	0,485
2011	0,48
2012	0,49
2013	0,58

Table 3: Degree of market power

HHI is easy to obtain, the only information needed is particular market shares. Computed HHI can be seen in Table 6. To obtain an estimate of inverse elasticity of demand, we have to run a regression

$$log(Q_{it}) = \alpha_0 + \alpha_1 log(price_{it}) + other factors + u_{it} \tag{4.14}$$

using two-stage least squares (2SLS) method, because $log(price_{it})$ is an endogenous variable. Inverse elasticity of demand is then $\frac{1}{\alpha_1}$.

Results of estimating (4.14) are reported in Table 5. The estimated elasticity is not very high. It means that the customers are not willing to abandon the three operators, even if they considerably increase price.

Using the result to compute $\mathcal{L}$, we get the values summarized in Table 3. Figure 6 shows the development of $\mathcal{L}$ over period 2000-2013. In 2000, the degree of competition was very low, because nearly half of the market was controlled by O2. Vodafone was a "new player", consequently its market share was negligible. As time passed, Vodafone has become a matching competitor for O2 and T-Mobile. Figure 4 reflects Vodafone's market improvement over time. In 2013, there was a sharp increase in O2's and T-Mobile's market shares and consequently in market power. They both experienced a succesful year and attracted a lot of new customers, mostly thanks to a new type of tariffs introduced by both operators.

Conclusion

In this bachelor thesis, we focused on the concept of market power and various methods of its measurement. Many of the models have nowadays important practical application, especially in antitrust policy. However, relying only on the estimation results can be misleading in practice, since simplifying assumptions are usually employed. The market should be assessed as a whole, with all its specifics and components.

The czech market of mobile operators has been chosen for empirical analysis of market power. Since nowadays there are even more active SIM cards than citizens, it is important for this market to work properly, i.e. with a sufficient degree of competition.

Measuring of market power was done in several steps. Firstly, the firms' conduct, i.e. market structure, was estimated. Using the model from Parker and Röller (1997) we concluded that czech mobile operators behave like Cournot oligopolists, on average. The estimation indicated the presence of economies of scale. This characteristic can have a nonnegligible effect on market power, since it acts like a barrier to entry.

Secondly, using Appelbaum's model and the fact that operators are (approximately) Cournot oligopolists, we derived an appropriate measure of market power that contains Herfindahl-Hirschman index and inverse elasticity of demand. HHI is easy to compute if particular market shares are known. Elasticity of demand has to be estimated.

Computed degree of market power can be seen in Table 3 and subsequently in Figure 6. The peak is in year 2000, which is not very surprising knowing historical background (as provided in Chapter 3). Whereas O2 and T-Mobile were quite established firms in 2000, Vodafone just entered the market. Therefore, the vast majority of market was controlled only by two firms. As time passed, the market power has fallen down. Vodafone got stronger in a sense of market competition, fourth operator entered the market in 2007 and 2012 was the beginning of new era - virtual operators. Market power slightly increased in 2013. That can be explained by introduction of unlimited tarrifs and subsequent increase in market shares, particularly in T-Mobile's and O2's ones.

Despite the steadily decreasing tendency of market power, its degree is still considerably high. As mentioned earlier, one reason can be economies of scale. Possible new entrants would be discouraged because of significant cost advantage of incumbents. If they decide to enter regardless the economies of scale, entrants will face the need to set higher prices in order to cover costs. Then, if we still assume homogenous product (which is most likely the case of mobile operators), it becomes difficult to compete with incumbents' lower prices. Of course, customers can choose a higher-price product, e.g. if they believe the product is of better quality or the brand appears more likeable to them. This kind of consumers' behavior can be a second reason for detected relative high degree of market power. O2, T-Mobile and Vodafone are nowadays well-established firms. Most of the customers trust the brands in a sense of quality. Moreover, many consumers are used to the three largest operators and their services and therefore probably do not want any change of provider even if they are a little bit dissatisfied.

To sum up, the estimation revealed a considerable degree of market power among the three largest czech mobile operators. However, we have to admit that our analysis contains many simplifications, such as assumptions about symmetric firms or homogenous product. The same goes for data, where marginal costs could have been approximated better than by average variable costs. Also missing data replaced by sample averages caused some damage in computation. Despite these limitations we believe that our conclusions approximately reflect the market's reality.

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Appendix

Market structures

In order to understand the market power's nature properly, it is convenient to briefly describe fundamental market structures. Each of them has its own specifics, including different behavior patterns of firms.

It is useful to have some kind of benchmark, to which we can compare other structures. Thanks to its desirable properties, our benchmark will be perfect competition.

With respect to the main topic of this work, next mentioned structure will be monopoly. Concerning market power, monopoly plays an important role - it has the highest possible degree of market power.

The last structure covered in this chapter is somewhat more realistic (and therefore more practical) than previous two - oligopoly. Oligopolist's degree of market power usually varies from a perfectly competitive firm's one to monopolist's market power. Three models will be discussed - Cournot, Bertrand and Stackelberg leadership model.

Perfect Competition

The first of the market structures, which are described in this chapter, is perfect (or pure) competition. Many assumptions have to be taken to properly describe this kind of firms' behavior and it is almost impossible to find an example of perfect competition among existing markets. However, it still plays an important role in a microeconomic theory as a base for comparison with other structures. Moreover, as will be stated later, firms in a perfectly competitive market have no market power – firm does not have an ability to affect the market output (or price) by switching its own output.[8]

First of all, some important assumptions have to be pointed out to help us describe the perfect competition's nature. Generally, we assume no barriers

[8]Each change in a firm's output is subsequently offset by other firms' change in output. Therefore, the overall output still remains the same

to entry to a perfectly competitive market. This ensures that firms can freely enter or leave the market. The consequence is crucial - firm cannot attain positive profit in a long run. Another assumption is a complete information. All firms have got the same information about available technology or prices of inputs. Furthermore, they all produce homogenous products, which are (at least approximately) perfect substitutes for each other. Last but not least, we assume that all firms want to maximize their profits as well as all consumers want to maximize their utility.

The first important characteristic, which differs perfect competition from other market structures, is horizontal individual demand curves, which the firms are facing. Horizontal demand implies that demand elasticity equals infinity and price is constant for all market participants – we say that firms are price takers. Moreover, a particular firm supplies only a small amount of a given product so that it cannot raise market price by restraining supplied quantity. In other words, firms have no market power.

What should be mentioned next is zero profit in a long run. Because of non-existence of barriers to entry, all extra profits

$$\pi^* = TR_i(y^*) - TR_i(y^*) > 0 \tag{1}$$

would trigger an entrance of more firms to the industry. Higher supply would push down the prices and existing firms would be forced to adjust their production. New firms would be coming to the industry until

$$\pi^* = 0 \tag{2}$$

$$LMC(y^0) = LAC^{min} = p^0 \tag{3}$$

where y^0 is an equilibrium output and p^0 is an equilibrium price. In the equilibrium, all firms yield zero profit in a long run and no other firms come to or leave the industry. This zero profit is a maximal one, because

$$LMC(y^0) = MR(y^0) \tag{4}$$

However, in a short-run firms are able to earn abnormal (positive) profits. The existence of fixed costs acts like an entry barrier, so that the number of firms entering the industry is restraint to those, which can cover their fixed costs. The number of such firms does not need to be sufficient to push down the prices resulting in zero profits.

Perfect competition's equilibrium is a Pareto-efficient allocation in the sense that "it is impossible to find some small change in the allocation of capital, labor, goods, or services that would improve the well-being of one individual in the market without hurting any others." (Pepall *et al.* 2008) On the contrary, next market structure will be shown to be inefficient in the Pareto way.

Monopoly

Monopoly belongs to a family of imperfect competition structures. Monopolist is usually the only firm in a market or with a few competitors with a negligible effect on monopolist's demand. Furthermore, monopolist possesses the highest possible degree of market power. It does not feel any consequences of changing its price or quantity on quantities or prices of other firms. Comparing to a perfect competition, monopoly can raise its price over marginal cost without losing all customers.

There are some similarities between monopoly and perfectly competitive market. The cost functions are the same as well as the main goal of market participants – minimization of costs and subsequent profit maximization.

Monopoly can yield a positive profit in a long run, usually because of the existence of barriers to entry (natural or artificial). Unlike a perfectly competitive firm, which maximizes profit by producing output such that price equals marginal cost, monopoly sets price over marginal cost and produces less quantity.

Profit maximization problem can be written as

$$\max_Q \pi(Q) = \max_Q (R(Q) - C(Q)) \tag{5}$$

$$MR(Q^M) = MC(Q^M) \tag{6}$$

$$\frac{dMR}{dQ}(Q^M) < \frac{dMC}{dQ}(Q^M) \tag{7}$$

where (6) and (7) are first and second order conditions, respectively. According to (7), MC has to raise quicker (or fall slower) than MR. Unlike a perfect competition case,

$$MR(Q^M) \neq p^M \tag{8}$$

because price is not a constant. Instead,

$$\begin{aligned} MR(Q) &= \frac{d(p(Q).Q)}{dQ} \\ &= p(Q) + Q.\frac{dp(Q)}{dQ} \\ &= p(Q)[1+\epsilon] \end{aligned} \tag{9}$$

where ϵ is the inverse elasticity of demand. Since monopoly faces a downward sloping demand curve, $\epsilon < 0$ and therefore must be

$$p(Q^M) > MR(Q^M) = MC(Q^M) \tag{10}$$

for equation (9) to hold.

We have shown that monopoly sets price over MC. Moreover, if monopoly's MC curve is identical with a supply curve of a perfectly competitive firm, monopoly produces less quantity of output but for a higher price.

On the contrary of perfect competition structure, we do not know monopolist's supply curve. More precisely, monopolist makes decisions based on his demand curve only.

Monopoly is in equilibrium Pareto-inefficient. See Figure 1.1 in Appendix. The point $[Q_C, p_C]$ represents perfectly competitive equilibrium. Consumers' surplus is $a + b + c$, while producer's one is $d + e$. Monopolist sets price p_m and lowers output to Q_m. Consumers' welfare loss is represented by parts $b + c$ and producer loses e (because of lower output) and gains b (because of higher price). Parts $c + e$ are then the deadweight loss, the loss in society's welfare.[9] However, this inefficiency does not stem from higher price, but from an unability of monopoly to conduct a perfect price discrimination. In this case, monopoly would produce the same quantity as a perfectly competitive

[9] Area c is lost by consumers, but not gained by producer. On the other hand, e is lost by producer, but not gained by consumers.

firm and the only difference would be a transition of welfare from consumers to producers.

Oligopoly

Oligopoly is a market structure with a few firms producing either homogenous or differentiated products and each feeling consequences of changing its own output on other firms' output and consequently on the overall market output as well. That is a basic difference compared to monopoly and perfect competition.

Three forms of oligopoly are described in this section. Cournot, Bertrand and Stackelberg models are going to be introduced as well as compared to the previous two market structures. For simplicity, we consider only two competing firms that produce homogenous products.

Cournot Duopoly

Cournot duopolists have quantity as decisive variable and, more importantly, set their quantity levels simultaneously. It means that none of them can make a move first and so commit to produce a particular quantity. This is a notable feature, because sequential setting of quantity would produce different conclusions than ours.

As stated earlier, oligopolists in general have conjectures about other firms' outputs when changing their own level of output. In Cournot duopolists case, it is assumed that a firm is not aware of any effect on a competitor's output. Formally,

$$\frac{dq_i}{dq_j} = 0 \qquad i, j = 1, 2 \text{ and } i \neq j \tag{11}$$

With respect to this characteristic, it is convenient to have some function that measures how firm 1 will react to an output level of firm 2. This function is called reaction function and is denoted as $R_1(q_2)$.

Duopolists have to make decisions about quantities based on their reaction functions. If one of them choose different quantity from that one, which corresponds to an intersect of reaction functions, resulting quantities will eventually converge to the intersect. It seems that this does not correspond to the assumption about simultaneous setting of quantity. But let us suppose that each firm know the reaction functions and that its competitor has the same information. Then, knowing that quantities converge to the intersect, firms can choose intersect's quantities from the start.

Resulting equilibrium $[q_1^c, q_2^c]$ is also called Nash equilibrium. It is an equilibrium, "for which no firm wishes to change its price (quantity) decision given those of all the other firms." (Pepall *et al.* 2008) Note that this definition says nothing about profits. Generally, firm can attain larger profit than that one in Nash equilibrium. Then we say that Nash equilibrium is not Pareto-efficient.

The comparison of Cournot to perfect competition and monopoly is as follows

$$Q^M < Q^C < Q^* \tag{12}$$

$$p^* < p^C < p^M \tag{13}$$

$$\pi^* < \sum_i \pi_i^C < \pi^M \tag{14}$$

where * denotes perfect competition, M monopoly and C Cournot duopolists. To sum up, Cournot is somewhere between perfectly competitive firms and a monopolist, regarding market power too.

Bertrand Duopoly

In contrast to Cournot duopolists, whose decisive variable is quantity, Bertrand duopolists choose levels of price. In previous two market structures, it plays no role whether a firm decides about quantity or price. But in Bertrand duopoly setting price instead of quantity forces firms to produce at $p = MC$.

In addition to homogenous product, let us assume the same constant marginal costs for both firms. When a firm decides about its price, clearly it would not set price above the monopoly's one. Suppose firm 1 chooses price p_1, which is below p^M, but above marginal cost. Then for firm 2 is the best reaction to set price p_2 slightly below p_1 and therefore conquer the whole market. In order to fight back, firm 1 sets price as well below its oponent's. The whole process will repeat until both firms have their price equal to marginal costs.

If the assumption about marginal costs was not made, the price war would have win the firm with smaller MC. If we also leave the assumption about homogenous product, Bertrand duopolists will produce at higher price than marginal cost, but lower than Cournot duopolists.

Stackelberg Duopoly

In this special case, firm 1 (leader) has an advantage of making the first move. It can commit to produce a particular quantity q_1^l. This commitment is believable, if, for example, high sunk cost makes it inconvenient to change the quantity afterwards.

The leader considers all follower's (firm 2) responses to leader's quantity, and chooses a quantity, which brings him the highest profit given the anticipated quantity of the follower. Follower then chooses exactly the anticipated quantity q_2^f, because it is the best reaction if follower believes in leader's commitment about output.

Comparing to the Cournot model, Stackelberg duopolists jointly produce more quantity for lower price (but the price is still above marginal cost). Interestingly, despite leader having larger profit than in Cournot case, the joint profit in Stackelberg competition is lower than in Cournot's.

Figures and Tables

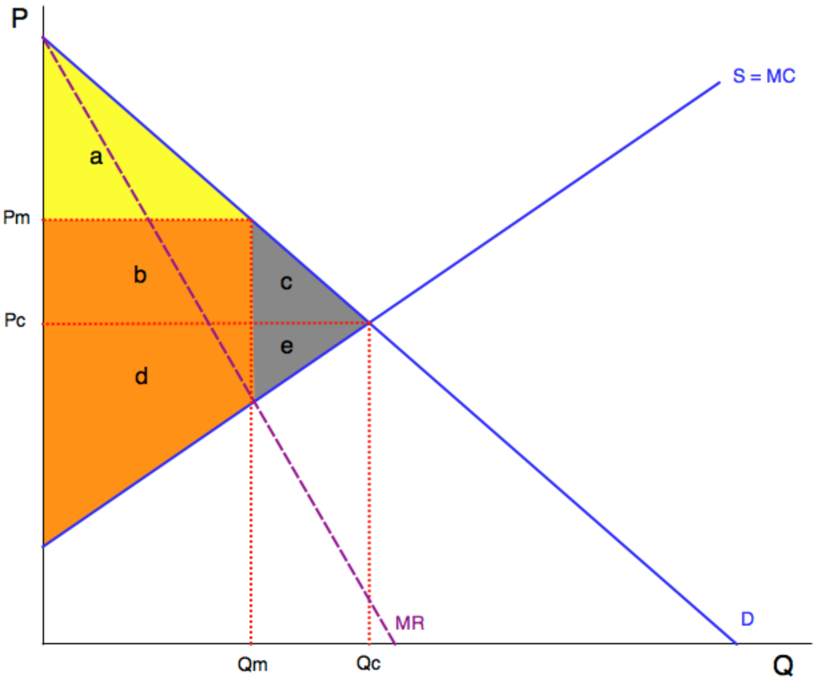

Figure 1: Deadweight loss in monopoly

Note: Picture is from mnmeconomics (2011).

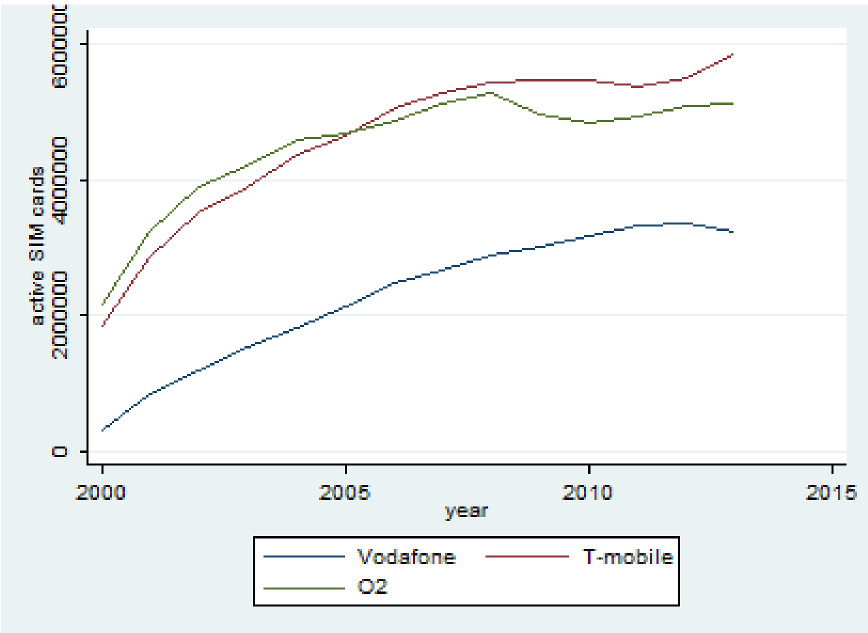

Figure 2: Active SIM cards over time

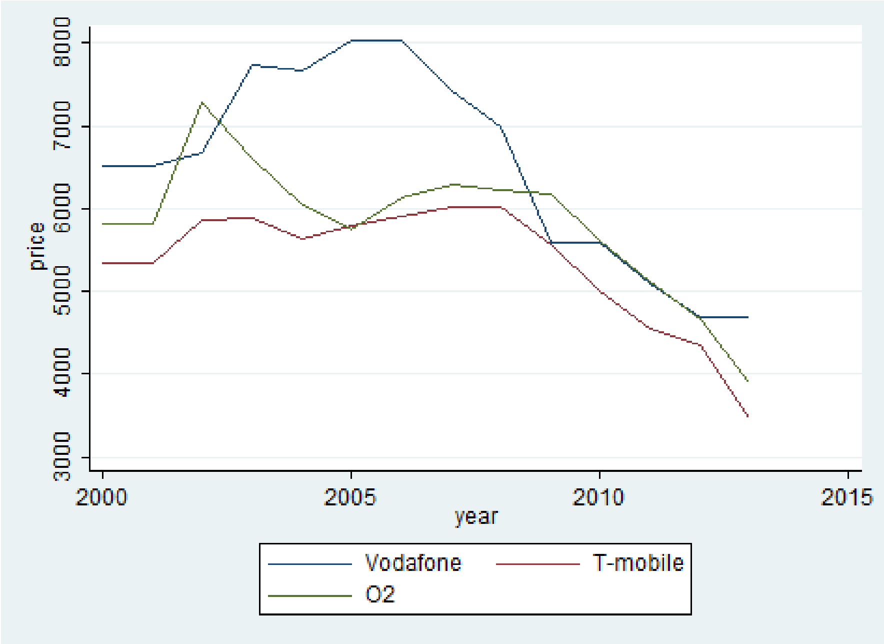

Figure 3: Price over time

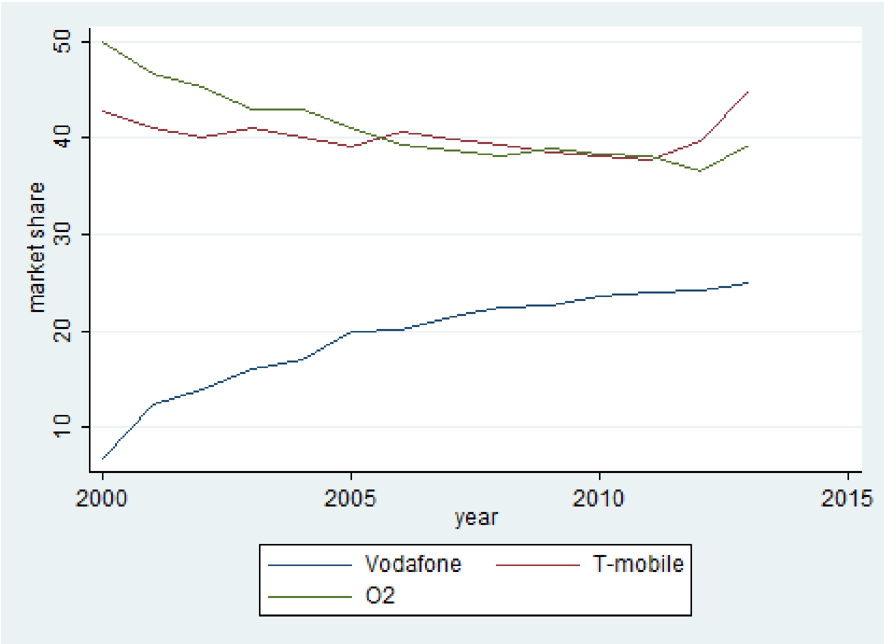

Figure 4: Market shares

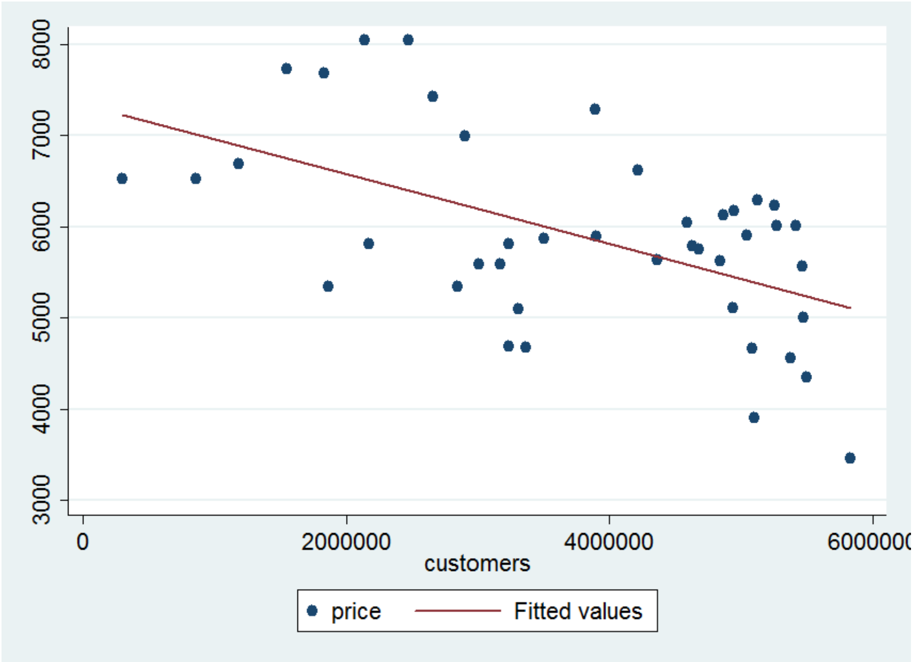

Figure 5: Market demand

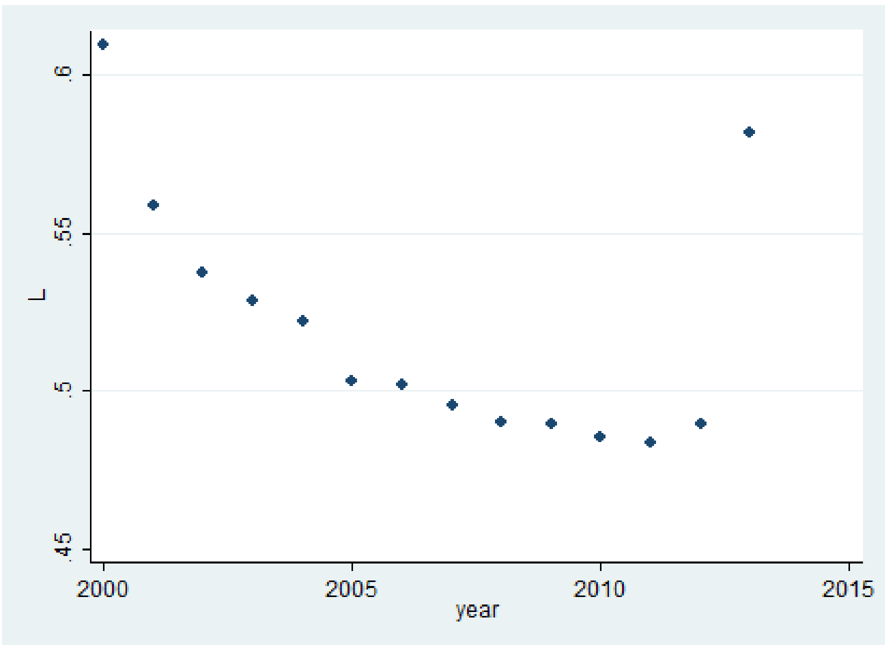

Figure 6: Degree of market power

Variable	**Min**	**Mean**	**Max**
price	3 456	5 892	8040
Q	300 000	3 796 000	5 831 000
pop	10,2	10,35	10,5
cons	1 191 000	1 658 000	1 999 000
unemp	6	8,69	10,3
MC	899,2	1 832	5 000
wage	227	2 379	5 437
energy	110,8	768,7	2 792
serv	3 399,12	9 196,44	13 048,2
repo	0,05	2,15	5,25
GDP	2 372 630	3 436 633	4 086 260

Table 4: Summary of data

	Estimate	**t-statistic**
Demand		
$Intercept$	14,55	8,48
$log(price)$	-0,72	-5,69
$log(GDP)$	1,14	2,41
$log(Q_{t-1})$	0,55	8,19
$log(serv)$	0,53	3,54
$log(cons)$	-1,64	-3,3

Table 5: Demand estimation results

Year	**HHI**
2000	4 366,9
2001	4 003,2
2002	3 850,8
2003	3 786
2004	3 738
2005	3 602,2
2006	3 596,7
2007	3 547,2
2008	3 510,1
2009	3 505,3
2010	3 474,3
2011	3 463,8
2012	3 507,9
2013	4 165,4

Table 6: Herfindahl-Hirschman index