Stockholm School of Economics
Department of Economics
Bachelor's Thesis in Economics

Supply and demand of electricity

An estimation of price elasticities for supply and demand in Sweden

Abstract

This thesis estimates yearly price elasticities of electricity from 1996 to 2009 using Two Stage Least Square analysis. A survey of previous research was conducted which finds that there are incentives for producers to regulate production according to price and that consumers are very price insensitive in general. No previous studies were found using Swedish total daily quantities to estimate both the supply and demand elasticities in a Simultaneous Equations Model using instruments for price. Our estimations show positive elasticities for the supply which is in line with profit maximizing behavior of electricity producers. The estimations for the elasticity of demand vary between being positive, negative or not significant. This may implicates that most consumers does not respond to price increases, information that could be useful for market regulating institutions.

Keywords: elasticity, Nord Pool, electricity price, supply and demand, electricity market

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1 Introduction

During the last century energy production has made great technological advances and has been a pillar in the development of modern society. Holding such a pivotal role in society the energy industry is constantly debated and faces great public scrutiny. Since electricity is an essential good for both industries and households its production must be upheld at all times. Due to its importance to society the electricity producing industry has been under tight government regulation in order to ensure a stable and fair market.

During the last two decades there has been a global trend towards liberalization where energy markets have been privatized. The government regulation of the Swedish energy market was manifested as large governmental entities with vast overcapacities that were perceived as being greatly inefficient. This resulted in higher end consumer prices and an inefficient market. Sweden deregulated the market for electricity in 1996 in order to increase competition within the market. Consequently the government wanted to achieve a shift in the intersection of supply and demand that would be more representative of a competitive market. The ultimate goal of this was to deliver electricity at lower prices to end consumers.

Before the deregulation consumers in Sweden only had the option to purchase their electricity from a local electricity distributor. These distributors were granted a local monopoly thus effectively restricting competition. The deregulation of 1996 meant that competition was introduced to the electricity market by removing the local monopoly of electricity distributors (Konkurrensverket 2002). This allowed companies to purchase electricity directly from Nord Pool and then sell it to consumers in all areas of Sweden. It was believed that this would increase competition and as conventional economic theory predicts, lead to lower prices and a more efficient use of resources.

Following the deregulation, electricity is traded on Nord Pool, which is owned, by the Nordic transmission system operators; Norway's Statnett SF, Sweden's Svenska Kraftnät, Finland's Fingrid and Denmark's Energinet.dk. At Nord Pool hourly power contracts are traded daily for physical delivery in the next day's 24-hour period. The price is based on bids and offers from all market participants i.e. the intersection point between the market's supply curve and demand curve (Energimarknadsmyndigheten 2006). There are also financial derivatives traded on Nord Pool. The whole Nordic market is served by Nord Pool and thus the market for electricity could be considered integrated between the Nordic nations.

In recent years there has been a lot of controversy in Sweden regarding the record profits of the electricity producing companies. Energimarknadsinspektionen (2006:13) holds the view that these profits are a result of the deregulation which may have allowed producers to increase and control prices. For example Vattenfall AB which is owned by the Swedish government makes big profits every year (Vattenfall 2010).

1.1 Aim

This thesis aims to estimate the yearly average price elasticity of supply and demand for the years 1996 to 2009. This will be done using data on quantity, price and other factors that correlates with quantity and price to define supply and demand equations in a Simultaneous Equations Model. Temperature, reservoir content and inflow will be used as instruments for price in a Two Stage Least Square analysis that will estimate the price elasticity. Knowledge of the price elasticity of electricity in could be useful when setting government policy such as environmental or taxation policy. Since there are no reasonable substitutes for electricity consumers are in a position of dependence to the few electricity-producing firms. If there is a low price elasticity of demand for electricity the consumer dependence on electricity may be exploited by the producing entities. Thus it is of interest to investigate the price elasticity in order to offer data that can be used in guiding government policy and partly explain the development in the price of electricity.

1.2 Scope

This paper will only deal with the spot price of electricity in Sweden traded on Nord Pool. The financial derivatives on electricity traded on Nord Pool are outside the scope of this paper. We have assumed that Nord Pool functions as an efficient market even though this is debated (Finansinspektionen 2005:4).

When investigating the price elasticity of electricity data for the years 1996-2009 is used due to restriction on available data. When using the spot price of electricity we have disregarded taxes and network fees that all consumers must pay in order to get access to the electricity grid infrastructure. The network tariff may be of importance in determining the price elasticity for consumers since it constitutes a substantial portion of the final price the end consumer pays. Also consumers may have different contracts with their electricity supplier. Contracts may vary by offering fixed- or variable rates. Hence, the price obtained from Nord Pool may not accurately reflect the price paid by the end consumer. In the study no distinction have been made between industrial consumption and private consumption since the data supplied by Nord Pool only contained figures on the total Swedish energy consumption.

1.3 Contribution

There are many previous reports and research papers that deal with the price of electricity and its relationship to demand. The reports from government agencies investigate the electricity market and the producers in order to explain both how well the market functions and what factors drive the price. Previous research papers try to explain how specific factors influence the electricity price and in turn how the price affects consumer demand. To the best of our knowledge no other research estimates both the yearly average supply and demand elasticities using Swedish data on total daily consumption. Hopefully this thesis will contribute to further examinations of supply and demand elasticities to better understand the market. Additionally it may guide regulating institutions in how to raise the price sensitivity of consumers, reducing the difference of supplier- and consumer power.

1.4 Outline

This thesis will be constructed in the following way. In chapter 2, the Nordic electricity market is described together with the price setting mechanisms. Also the factors affecting price are presented. Chapter 3 presents previous research relevant to this thesis. Chapter 4 explains the economic theory underlying the discussion of the electricity price and the electricity market. Chapter 5 describes and discusses the methods and data used in the analysis while the results are presented and interpreted in chapter 6. The possible underlying reasons of these findings are discussed in chapter 7. In chapter 8 the conclusions of this thesis and suggestions for future research are presented.

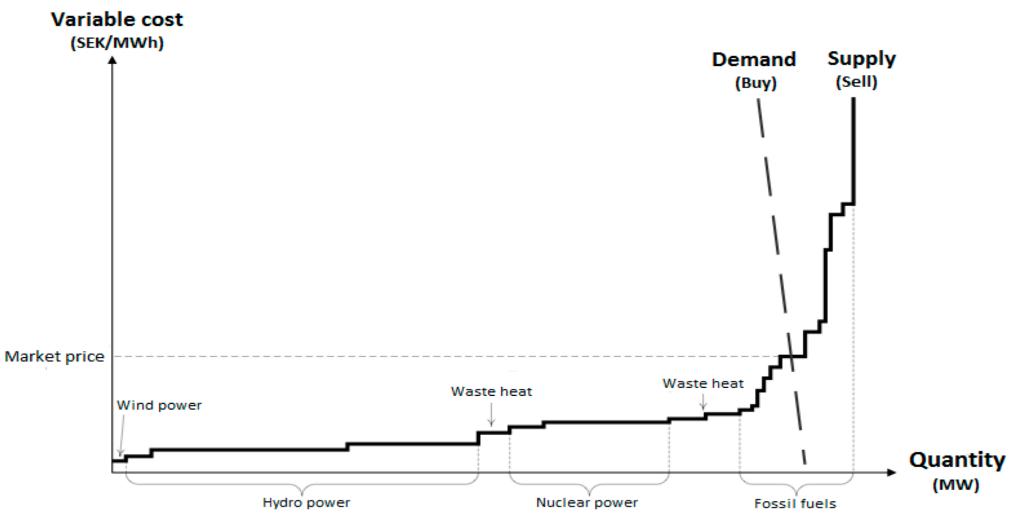
2 The Nordic electricity market

In this chapter an overview of the electricity and its price setting mechanism is provided. Additionally factors affecting price are presented and explained.

2.1 Sources of electricity production

The main sources for electricity in the Nordics are hydro- and nuclear power (Energimarknadsinspektionen 2009). Both these technologies are characterized by relatively low marginal cost compared to other means of electricity production. The production of electricity from nuclear power differs from other forms of electricity production since it is designed to produce at a constant capacity, thus the production from nuclear power does not vary in the short-term. Hydro, wind and fossil production have a more variable utilization of production capacity. This is of importance since the price of electricity offered on Nord Pool is set by the marginal cost of the most expensive power source in use as seen in figure 1.

Figure 1. Price setting mechanism of the spot price of electricity on Nord Pool



Note 1. The spot price is determined by the energy source with the highest marginal cost. Adapted from Energimarknadsinspektionen p. 7 2006:13 (authors translation).

When production from hydro- and wind power decreases, production from fossil fuels is used instead in order to compensate. As electricity from fossil fuels is more costly to produce the price of electricity will increase.

The demand of electricity is correlated to the outside temperature and thus varies greatly during the year with demand being higher during winter (Energimarknadsinspektionen 2006:13). When demand increases to such levels that other sources of energy production cannot meet demand, electricity from fossil fuels is used and sets the price. Thus the higher demand leads to a price increase. However the electricity from coal and other sources of fossil fuels play a small role in the overall energy production even though it is price setting. Electricity produced from coal is roughly 1.6% of the total yearly production in Sweden and is mainly used to meet peaks in demand (Vattenfall 2011).

2.1.1 Nord Pool

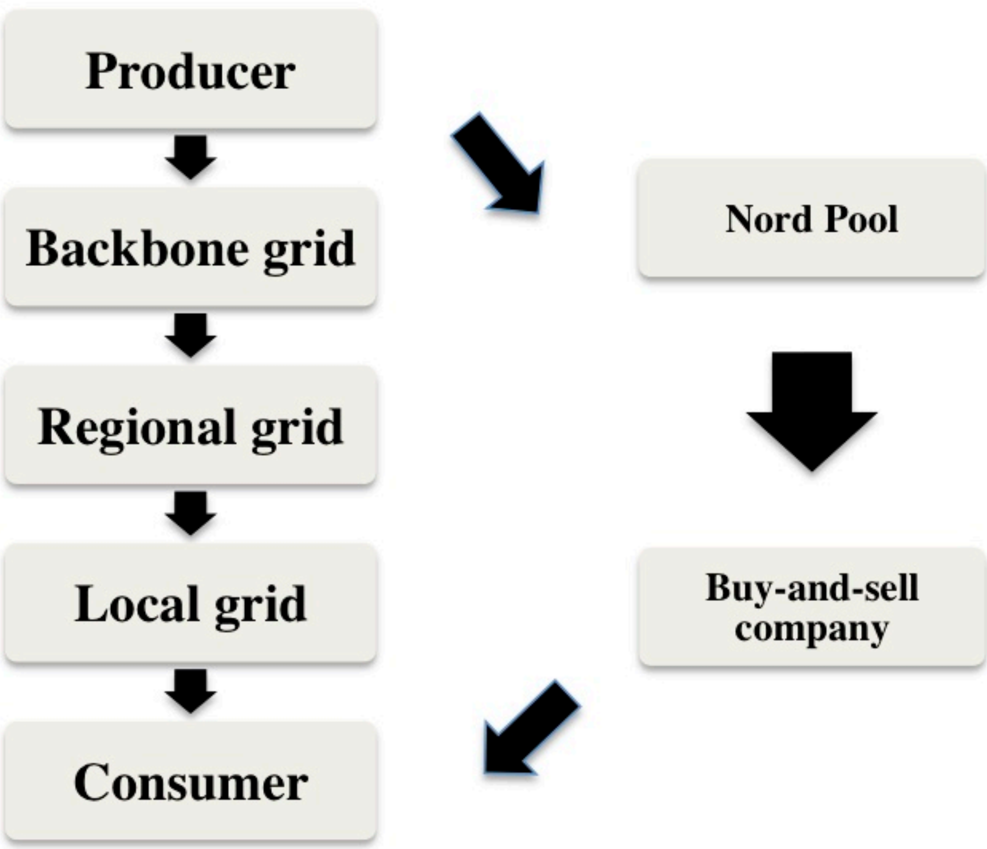
On Nord Pool electricity for the Nordic region is traded on an hourly basis where suppliers place offers for the coming 24 hours. The offers from suppliers and the bids from buyers are matched and an equilibrium price is found, which is referred to as the System Price. However occasionally areas are insufficiently supplied resulting in a deficit of electricity in a particular area. In those instances a regional price is used in the deficit areas instead which is called Area Price and is usually higher. The higher Area Price is used to increase the supply in that area since producers will be more willing to allocate electricity to areas where the price is higher. This will ultimately lead to the flow of power from the low price area to the high price area so that all areas are sufficiently supplied and the price is equalized between the areas.

2.1.2 Producers and consumers

The electricity market consists of producers, consumers, buy-and-sell companies and an infrastructure that transfers electricity. There are several producers of electricity, most notably Vattenfall, E.ON Sweden and Fortum who stands for roughly 90% of the electricity produced in Sweden (Energimarknadsinspektionen 2009). The buy-and-sell companies cater directly to consumers by purchasing electricity on Nord Pool and selling it to the end consumer. However the power producing companies are vertically integrated and also participate in this market by selling their electricity directly to consumers.

The infrastructure consists of the electricity grid that function as a channel where electricity is transported from producers to end consumers (see figure 3). The Swedish electricity grid is divided into the backbone-, regional- and local grids. The backbone grid is owned and operated by Svenska Kraftnät AB which is a government owned company whereas the regional grids are mainly owned by the large electricity producers Vattenfall, E.ON and Fortum. Currently the Swedish local electricity grid is owned by many small companies where each company has the sole right to distribute electricity in their designated areas. Consumers are obliged to pay a fee to the network companies when buying electricity in order to transfer the electricity.

Figure 2. Overview of the Nordic electricity market



Note 2. Source: www.svk.se/om-oss.

2.2 Factor that determine Swedish electricity price

The volatility of the electricity price is attributed to the many factors that influence supply and demand. One aspect of electricity is that unlike other traded commodities, electricity cannot be stored. Thus the production and the consumption of electricity have to occur simultaneously. Nuclear power is mostly designed to always operate at full capacity and thus variable supply of electricity is determined by hydrological factors, except for occasional shut downs of nuclear facilities. The supply also depends on the possibility of importing electricity produced in other nations.

2.2.1 Integration with continental Europe

Nord Pool is partly integrated with continental Europe and particularly Germany. This interaction leads to a partial harmonization of prices. Energimarknadsinspektionen (2006:13) describes rising spot prices in continental Europe during 2005 that led to increased demand for the relatively cheap electricity produced and available on Nord Pool. To meet this increased demand relatively more expensive means of production had to be used leading to higher prices. Energimyndigheten (2005) postulates that the import demand from Germany was unsaturated and if their demand had been fully met, the price of electricity between Nord Pool and Germany would be fully equalized.

In the report we have taken into account the effects of export from Sweden and import to Sweden using dummy variables if export or import occurs.

2.2.2 Hydrological factors

Hydro power is harnessed from the flow of moving water through turbines that generate electricity. The water is usually dammed in a reservoir and is allowed to flow through turbines under controlled forms. Thus the production of electricity is dependent on the amount of dammed water in the reservoir that is released. This means that precipitation, inflow of water and the volume of reservoir content are important factors determining the supply and consequently the price of electricity. Since electricity from hydro power is produced at relatively low cost, and account for about half of the total electricity produced in Sweden (Energimarknadsinspektionen 2009), an increase of inflow could lower the price by a large amount. The volume of dammed water follows a seasonal pattern with lower levels during winter and higher during summer. This is due to the lower precipitation during winter as well as an increased outlet of dammed water in order to produce electricity and meet the increasing demand that accompanies every winter.

2.2.3 Temperature and daylight

In the Nordic energy market electricity demand is very much affected by temperature due to the fact that many households and industries use electricity for heating purposes. Temperature changes in Sweden are one of the main sources of the seasonal shifts in electricity prices, with high prices during the winter and low prices during the summer. The high demand of electricity during cold winters leads to a shortage of electricity supply in the domestic market and electricity need to be imported at higher prices which raises the electricity price. The opposite is true during summer with high outside temperatures (Energimarknadsinspektionen 2006:13). One factor that also contributes to the seasonal variations of electricity consumption is the duration of daylight. The winters in Sweden are characterized by short hours of daylight, especially in the north, and thus more electricity is used for lighting. The time between sunrise and sundown during a day is therefore accounted for in our econometric model.

2.2.4 Emission permits

The Kyoto Protocol is international agreement that limits the greenhouse gas emissions of 37 industrialized nations. It was adopted in 1997 and enforced in 2005. In the Kyoto Protocol each nation commits to limit their emissions of greenhouse gases, most notably carbon dioxide. The Swedish Environmental Protection Agency (Naturvårdsverket) allocates emission rights which certain facilities must have in order to operate. Each emission right allows the holder to emit one ton of carbon dioxide.

Since the trade of emission permits are traded at various markets and sold bilaterally reliable historical prices could not be found. Also in recent years there has been an abundance of emission permits which has led them to be marginalized in electricity production (Chappin and Dijkema 2011). In regards to above mentioned emission permits have been excluded from the statistical model in this thesis.

3 Previous research

In this chapter previous research relating to the electricity market is presented. The first part deals with governmental reports and the second with research papers.

The amount of studies made on the price elasticity of electricity is vast both in the amount of countries studies have been conducted in and in the various statistical models used. Summarizing the results exceeds the scope of this thesis. What can be said is that studies performed in other countries may show different results than studies in Sweden since elasticity of supply and demand are very much dependent on the specifics of the marketplace. The use of different statistical methods mostly depends on the data used where different data requires different statistical approaches. Therefore it is difficult to compare results between different reports (ELFORSK 2004:18). Below are selected reports and research studies presented that we believe are the most relevant to our thesis.

3.1 Reports

The Swedish Energy Markets Inspectorate (Energimarknadsinspektionen) published in 2006 a report, on behalf of the Swedish government, regarding the Swedish and Nordic electricity market with focus on price and competition. The report tries to explain the last decades' price increase and its relation to competition from the view of the electricity companies and their cost structure. The conclusion is that the most important factors affecting the price on the Nordic energy market are; hydrologic balance, production, exchange with continental Europe, commodity prices, and trade with emission rights (ER 2006:13). The report also concludes that prices on the electricity market are volatile with temporary and sudden price level fluctuations due to sudden rises in demand. This results from the fact that it is not possible to store electricity and that the demand is relatively price insensitive, at least in the short run.

In the report Övervakning och transparens på elmarknaden (Energimarknadsinspektionen 2010:21) The Swedish Energy Markets Inspectorate investigates the supervision and transparency of the electricity market in Sweden. One of their conclusions is that many consumers find the electricity market complicated and difficult to understand which impairs the consumer trust for the market. The electricity market needs customers that actively participate in order to find a balance of power between producers and consumers. This stresses the importance of customers being up to date on recent developments. The report does not fully answer why consumers distrust the market but states that all actions leading to increased transparency and supervision contributes to increased trust. The report also analyses the supply side of the electricity market and the advantages vertically integrated companies have towards independent sellers of electricity as well as the dangers of co-ownership of power plants. Vertically integrated companies, which control both production and sales, have access to all market influencing information, which contradicts the elementary condition for a competitive market where all actors should simultaneously have access to all the information. Co-ownership limits effective competition in several ways. Elisabeth Svantesson, member of the Swedish Parliament, said that "One condition for the electricity commerce to be an effectively functioning market is that there is some uncertainty for the producers regarding both the supply- and demand situation when prices are set." (authors translation).

Doorman *et al.* (ELFORSK 2004:18) reaches in their report several conclusions about the price elasticity of demand and the electricity market. They state that short-term price elasticity is virtually inexistent in general. There is to some extent an affect of price on demand but only to consumers that are actually directly exposed to price changes, which few are. For households the reports states that it can be assumed that the price elasticity is equal to zero since none or very few customers are exposed to actual spot prices. For electricity intensive industry there is however some price elasticity when spot prices rises above 1 SEK per kWh. During the years before the report was written this had happened only a few times thus it was difficult to measure exactly how much the consumption was affected. There is however evidence that the demand is price elastic in the long run but the estimates differ greatly depending on different methods and models used for estimation. In the future Doorman *et al.* believe that consumers will be more sensitive to price changes in the short-term if they are more exposed to spot prices.

3.2 Research papers

Valor et al (2001) has conducted research about the relationship between temperature and electricity load in Spain. The report uses data on temperature and electricity load from the peninsula of Spain. They also state that outside air temperature is the most important weather variable affecting electricity demand whereas other factors, for instance humidity and wind speed, may be used as correcting variables. The temperature variable is calculated as the arithmetic mean of the maximum and minimum daily temperatures. Since data on regional electricity demand was not available, a population-weighted temperature index was created due to the fact that temperature changes in densely populated areas will have a relatively greater effect on electricity consumption. The report concludes that electricity consumptions correlates with temperature and also correlates with demographic and socio-economic factors. In addition, effects unrelated to weather such as seasonal effects (weekly and holiday effects) also effect electricity consumption. The analysis also reveals that the sensitivity of consumption to temperature has increased over time.

Damsgaard published in his dissertation in 2003 the study Residential Electricity Demand – effects of Behavior, Attitudes and Interest. The study aims to measure the explanatory value of different variables for the household demand of electricity. Information about economical, technical and demographic factors was retrieved from publicly available data. This was amended with information from household surveys to characterize their behavior, attitudes and interest in energy issues. With this detailed data Damsgaard found that information regarding amount of electricity consuming appliances in household is useful in addition with demographic and economical data for estimating consumer demand. The report finds that attitudes and knowledge in energy conservation only reduces demand in households with a high energy consumption i.e. households with a high level of consumption, have an interest in energy conservation, which seems to reduce electricity consumption.

Mark G. Lijesen (2007) estimates real-time price elasticity of electricity in the Netherlands using data from 2003. The paper estimates a function explaining the total hourly electricity demand from the spot price and other factors affecting demand. The estimation is done on peak load hours only. Examples of variables used are dummies for time of day, maximum day temperature, daylight and dummies for public holidays. A special characteristic of the Dutch electricity market is that only 15 percent of the electricity is traded on the spot market. The rest is traded through bilateral contracts between consumers and suppliers that are often linked to the spot price. By looking at the total demand the study aims to capture both the effects of the spot market and the bilateral market. The report recognizes the problem of the price variable being correlated with the error and solves this by estimating a Two Stage Least Square regression using lagged price as an instrumental variable for price. Two estimations were made using both a linear and loglinear approach. The results show a price elasticity of -0.0014 for the linear specification and -0.0043 for the loglinear.

4 Theoretical framework

In this chapter the theoretical framework used in the thesis is presented and explained starting with elasticity and moving on to market mechanisms.

4.1 Elasticity

In economics elasticity is a tool to measure proportional change in one variable to change in another. It is a widely used concept and is used to explain changes in behaviors such as how much consumption of a good will change when price or income increases.

4.1.1 Price elasticity of demand

Price elasticity of demand (PED) is a measure of responsiveness in demand with regards to price changes. The *law of demand* states that an increase in price of a good will be accompanied with a decrease in demand of that good, resulting in a negative PED. It is calculated as described below:

$$\boldsymbol{E_d} = \frac{\%\ \boldsymbol{change\ in\ demanded\ quantity}}{\%\ \boldsymbol{change\ in\ price}} = \frac{\Delta \boldsymbol{Q_d} / \boldsymbol{Q_d}}{\Delta \boldsymbol{P} / \boldsymbol{P}}$$

The demand for goods can be categorized as elastic or inelastic where a good is generally considered elastic if the PED is greater than 1 in absolute value. A PED of -1 means that if the price increases 1 percent it will lead to a decrease in demand of 1 percent. Thus if PED equals 0 then a price increase will not lead to a change in demand. Such a good would be considered inelastic (Pindyck and Rubenfeld 2009).

4.1.2 Price elasticity of supply

Price elasticity of supply (PES) measures the relationship of changes in supplied quantity to changes in price. It is calculated as described below:

$$\boldsymbol{E_s = \frac{\%\, change\ in\ supplied\ quantity}{\%\, change\ in\ price} = \frac{\Delta Q_s / Q_s}{\Delta P / P}}$$

The *law of supply* states that suppliers will supply a larger quantity of a good at higher prices of that good. As a result of this most supply curves are upwards sloping i.e. the PES is positive. The supply of a good is considered elastic if PES is greater than 1 in absolute value. This means that an increase in price will lead to a higher proportional increase in supply. For example if the price of a good increases by 1 percent and it results in a 3 percent increase in supplied quantity, that good will have a PES of 3. A good with a PES of less than 1 is considered price inelastic. This means that even though the price increase is accompanied by an increase in supplied quantity it is less than the proportional increase in price (Pindyck and Rubenfeld 2009).

4.2 Monopoly and oligopoly

A monopoly is defined as a situation where a single company exerts such a control over a market that it is able to operate without competition and acts as a price setter by regulating supply. Whereas in efficient markets prices are set by actual supply and demand. Such situations can occur for example due to great economies of scale or government regulation. Oligopoly is where a few companies collaborate to exert dominance and control over a certain market. Most nations have laws limiting oligopolies, however in some instances government law protects monopolies for certain services and products that are essential for society.

4.3 Market efficiency

In order to investigate the price elasticity it must be decided if Nord Pool is an efficient and liquid market where supply and demand can meet without restrictions. According to the efficient market hypothesis (Malkiel 2005) the criteria for an efficient market is that the price is in accordance with all available information. It is assumed that all information is known to all participants in the market and it is thus impossible to make profits by trading solely on basis of known information. Also in an efficient market the price moves instantly with the addition of new and relevant information. Opinions on whether Nord Pool is an efficient market differ. According to Finansinspektionen (2005:4) Nord Pool is not a completely efficient but NordReg (2009), which consist of electricity market regulators from the Nordic countries, held the opinion that the electricity markets function properly. According to Deng (2005) Nord Pool is not an efficient market due to the high proportion of hydro power where hydro reservoir inventory is withheld, distorting prices. For the purposes of this thesis Nord Pool is considered to function as an efficient market.

5 Method and data

This chapter accounts for the statistical methods used when estimating the elasticity. It presents the equations used and also the data.

The price of electricity featured frequently in the Swedish media during the winter of 2011 and particularly the powerlessness of consumers to affect high prices. Also the electricity production companies were making huge profits and there were many speculations of weather they were misusing their market power or not. This encouraged us to write our thesis in the field of electricity prices. To investigate how the electricity price and quantity is set, and how it has changed since 1996, the relationship between price and quantity needs to be investigated. Earlier research was studied to gain knowledge in how the Swedish electricity market functions in practice and which variables were relevant to our investigation. The price setting mechanisms are of interest for consumers since it illuminates how they can make decisions to lower their electricity cost and the overall price level. It is also of importance for market regulating institutions to gain a deeper understanding of how the price market functions consequently improving the basis for regulation. To find a new approach we decided not to only estimate the price by using a Multiple Regression Model, which has been done before (Ahlengren *et al.* 2007). Electricity is traded at the marketplace Nord Pool where the price and quantity of electricity is set by the supply and demand. Therefore we decided to analyze the electricity market using the economic theories of supply and demand. To estimate the supply and demand elasticities two Multiple Regression Models were estimated in a Simultaneous Equation Model using Two Stage Least Square analysis with instrumental variables. When trying to statistically estimate the supply and demand curve of a good there is a problem with endogeneity due to the simultaneity of the functions. This happens because one or more of the explanatory variables is jointly determined with the dependent variable. In our case quantity is jointly determined with price through the equilibrium mechanism. To avoid the problem with endogeneity the Simultaneous Equation Model of supply and demand can be estimated with instrumental variables. Instrumental variables and the method of solving Simultaneous Equation Models are described later on. When conducting our analysis we first specified our supply and demand equations and chose appropriate instruments for price in both equations. Two estimations were done on the equations; one with the equation in its normal form and one where price and quantity were in logarithmic form to capture elasticity. Only the logarithmic estimation was used in the analysis. The simultaneous equation models were estimated for every year and for every year the goodness of fit of the instruments were also tested.

5.1 Instrumental Variables

This part follows chapters 15 and 16 in the statistical textbook by Wooldridge (2009). Instrumental Variables (IV) are often used when there is an omitted variable bias in Ordinary Least Squares (OLS) estimations. When one of the explanatory variables is missing you can use a proxy variable but it is not always easy to find a good proxy. Consider the equation

$$\boldsymbol{y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + e}$$

where x_2 is a variable that cannot be measured and a good proxy cannot be found. Then the variable x_2 will be put in the error term and the regression model will be

$$\boldsymbol{y = \beta_0 + \beta_1 x_1 + u},$$

resulting in a biased OLS estimation and an inconsistent estimator of β_1 if x_1 and x_2 are correlated. If this is the case an instrumental variable z can be used for x_1 which has to satisfy two assumptions: z is uncorrelated with u,

$$\mathbf{1.}\, \boldsymbol{Cov(z, u) = 0},$$

and z has to be correlated with x_1,

$$\mathbf{2.}\, \boldsymbol{Cov(z, x_1) \neq 0}.$$

z is called the instrumental variable since it acts as an instrument for x_1. In our supply estimation temperature will be used as an instrument for price since it is assumed not to correlate with uncontrolled factors affecting supplied quantity and it correlates with price. Testing if an IV is uncorrelated with the error term is difficult and it has to be justified using economic behavior. Testing for the second condition is easy using a simple regression model

$$\boldsymbol{x_1 = \pi_0 + \pi_1 z + v}.$$

Assumption 2 holds if $\boldsymbol{\pi_1 \neq 0}$ and we can reject the null hypothesis $\boldsymbol{H_0: \pi_1 = 0}$. The same reasoning as above applies to a situation where it is suspected that one of the explanatory variables is endogenous i.e. correlated with the error,

$$\boldsymbol{y_1 = \beta_0 + \beta_1 y_2 + \beta_2 z_1 + u_1},$$

where y_2 is endogenous and z_1 is exogenous. However, here z_1 cannot be used as an instrument for y_2 since z_1 is an explanatory variable in the equation and another variable, z_2, that satisfies condition 1 and 2 is required as an instrument. To test if there is a partial correlation between z_2 and y_2 the following equation is set up:

$$\boldsymbol{y_2 = \pi_0 + \pi_1 z_1 + \pi_2 z_2 + v_2.}$$

Where the condition that $\boldsymbol{\pi_2 \neq 0}$ together with the assumption that z_1 and z_2 are uncorrelated with v_2, based on economic reasoning, must be satisfied.

5.2 Two Stage Least Squares

To perform an OLS regression analysis with IV's, Two Stage Least Squares method (2SLS) can be used. The first stage uses the equation above to estimate an IV for y_2:

$$\boldsymbol{\hat{y}_2 = \hat{\pi}_0 + \hat{\pi}_1 z_1 + \hat{\pi}_2 z_2.}$$

The IV is further denoted as y_2* and is used in stage two to perform an OLS estimate of y_1:

$$\boldsymbol{y_1 = \beta_0 + \beta_1 y_2^* + \beta_2 z_1 + u_1.}$$

It can be said that the first stage "purges" y_2 from its correlation with u_1 prior to the OLS estimation with the IV (Wooldridge 2009).

5.3 Simultaneous Equations Models

The most important aspect when using Simultaneous Equations Models (SEMs) is that each equation should have its own ceteris paribus (all other things held constant) interpretation (Wooldridge 2009). The classic use of SEMs is with supply and demand functions where the supply and demand of a good is determined by a number of factors. Following functions are used and constitute a Simultaneous Equations Model:

$$\boldsymbol{y_s = \alpha_1 x + \beta_1 z_1 + u_1}$$
$$\boldsymbol{y_d = \alpha_2 x + \beta_2 z_2 + u_2}$$

where y_s and y_d are quantities supplied and demanded respectively. Both depend on the variable x and different exogenous variables z_1 and z_2 which are called observable *supply and demand shifters*. For the equation system to be useful it must be assumed that $\boldsymbol{\alpha_1} \neq \boldsymbol{\alpha_2}$ so that the supply and demand curves differ. Another important point is that the exogenous variables z_1 and z_2 must be in their respective equations since otherwise there is no possibility to tell the supply and demand function apart. Each equation stands on its own and has its own interpretation but they become linked in a system because the observed x value is determined by the intersection between supply and demand:

$$\boldsymbol{y_s = y_d}.$$

To estimate the parameters in a SEM equation one condition is that each explanatory variable is uncorrelated with the error term and thus an instrumental variable is needed for the endogenous variable *x*. If the economic behavior of the equations allow for it z_1 can be used as an instrument for x in the demand function and z_2 can be used as an instrument for x in the supply function. The variable $z_1$is assumed not to appear in the demand equation and vice versa with variable z_2 so that we have imposed exclusion restrictions on the model (Wooldridge 2009). Also the first equation can only be identified if the second equation contains at least one exogenous variable that is not in the first equation and vice versa. This is called the rank condition (Wooldridge 2009). Once the equations and instrumental variables have been identified the equations are estimated by the Two Stage Least Squares method separately.

5.4 Variables and econometric model

The variables used were based on both previous research and our own reasoning. Below follows and account for all variables used in our econometric model.

$\boldsymbol{price_{infl_i}}$: $\boldsymbol{Daily\ spot\ price\ on\ elctricity\ adjusted\ for\ inflation}$

$\boldsymbol{quantity_i}$: $\boldsymbol{The\ quantity\ of\ electricity\ produced\ and\ consumed\ in\ Sweden}$

$\boldsymbol{temp_i}$:

$\boldsymbol{Weighted\ average\ daily\ temperature\ in\ Sweden}$

$\boldsymbol{precipitaion_i}$:

$\boldsymbol{Total\ daily\ percipitation\ at\ chosen\ locations}$

$\boldsymbol{snowdepth_i}$:

$\boldsymbol{Average\ total\ snowdepth\ at\ chosen\ locations}$

$\boldsymbol{Content_i}$: $\boldsymbol{Total\ daily\ reservoir\ content\ in\ Sweden}$

$\boldsymbol{Inflow_i}$: $\boldsymbol{Total\ daily\ inflow\ of\ water\ to\ reservoirs}$

$\boldsymbol{Daylight_i}$: $\boldsymbol{Weighted\ average\ of\ duration\ of\ daylight\ in\ Sweden}$

$\boldsymbol{export_i}$: $\begin{cases} \boldsymbol{1. If\ export} \\ \boldsymbol{0. Otherwise} \end{cases}$

$\boldsymbol{import}_i$: $\begin{cases} 1. If\ import \\ 0. Otherwise \end{cases}$

$weekday_i$: $\begin{cases} 1. If\ weekday \\ 0. If\ weekend \end{cases}$

$month_i$: $\begin{cases} 1. If\ month\ i \\ 0. Otherwise \end{cases}$

After the variables were chosen and the data had been collected the supply and demand equations were specified. Some variables are assumed to only affect the supplied quantity and some only the demanded quantity. The supply equation was specified as follows:

$$quantity_i = \alpha_0 + \beta_1 price\_infl_i + \beta_2 content_i + \beta_3 inflow_i + \beta_4 precipitation_i + \beta_5 snowdepth_i + \delta_6 export_i + \delta_k month_{ki} + u_i$$

The demand equation was specified as follows:

$$quantity_i = \alpha_0 + \beta_1 price\_infl_i + \beta_2 temp_i + \beta_3 temp_i + \beta_4 daylight_i + \delta_5 import_i + \delta_6 weekday_i + \delta_k month_{ki} + u_i$$

To test the equations in the Simultaneous Equation Model the price variable was instrumented according to statistical theory. One of the variables from the supply equation was used as an instrument for price in the demand equation and vice versa. In the supply equation *temp* was chosen as an instrument for *price_infl* and in the demand equation *content* and *inflow* were chosen as instruments for *price_infl*:

$$supply: \qquad price\_infl_i^* = temp$$

$$demand: \qquad price\_infl_i^* = content + inflow$$

Temperature was chosen as an instrument for price in the supply equation as earlier research shows that temperature is correlated with price. Also temperature should not correlate with the supplied quantity, or other factors affecting the supply, since most forms of energy production produces regardless of temperature. One could question whether temperature affects hydropower or not. We believe that there is an effect of temperature changes to hydropower but that it is offset by the ability of hydro power producers to store water in the reservoirs. In addition inflow and content are controlled for in the model. In the demand equation content and inflow was used to instrument price since these factors should correlate with price. More access of water should lead to increased hydro power production, thus lower price. Content and inflow is assumed not to correlate with the demanded quantity, or factors affecting the demand, since consumers in general do not have access to this information. The demand is more dependent on temperature which is controlled for in the model. There is a problem however using the inflow and reservoir content as instruments for price. Due to the fact that electricity cannot be stored as opposed to water, energy producers can control the hydropower production in order to maximize profits (Deng 2005). For the purposes of this paper the possible effects of producers limiting production are disregarded.

When the equations and instrument had been specified multiple regression analysis was performed in STATA using Two Stage Least Squares method in accordance with the Simultaneous Equations Model. In STATA the first stage regression is shown and the instruments can be evaluated for their goodness of fit. Multiple regression analysis was also performed using the same equations but with the *quantity* and the *price_infl* variables in logarithmic form to get the supply and demand elasticities. The results from the regressions were then exported from STATA to Excel where the data is more easily handled.

5.5 Data

The data used for analysis has been gathered from several different sources. Most of the data contained daily measurements, in other cases the data was calculates as a daily average. Data from the years 1996-2009 was gathered and imported to an Excel worksheet where it was formatted to fit the analysis. The data was then exported to STATA for further analysis.

5.5.1 Temperature

The temperature data was gathered for the years 1996-2009 from the Swedish Metrological and Hydrological Institute's website www.smhi.se. SMHI has 52 measuring stations spread out across Sweden and data from the measuring stations in Stockholm, Gothenburg, Malmö, Sundsvall and Luleå was collected to take temperature variations across the country into account. Due to difference in population surrounding the measuring stations temperature changes will affect the electricity demand differently depending on where the changes occur (Valor et al 2001). Since Stockholm for example has a much greater population than Luleå, temperature changes in Stockholm would affect a larger amount of people and thus affect demand in a large proportion. To account for this the samples have been weighted according to the population in the relevant community. Population data was gathered from SCB (2011a).

The validity of the data is considered very high since SMHI is a respected and trusted institution. Also SMHI is the only organization that measures temperature across Sweden on a daily basis. The weighted average temperature variable can be questioned on whether it accurately captures the actual average temperature in Sweden. Even so, we decided that it was most suited for the econometric model to only have one temperature variable and calculated it to the best of our abilities.

5.5.2 Duration of daylight

The duration of daylight during the day affect electricity consumption since electricity is used for lighting. The duration is used in our analysis to control for differences in

electricity consumption between different times of the year when the temperature can the same but the duration of daylight may differ. The data was collected from the same geographical places as temperature and weighted in the same way. Our definition of the duration of daylight is the time between sunrise and sundown and the data was gathered from the website www.stjarnhimlen.se.
The validity of this variable is considered high since the time of sunrise and sundown are very well established and the data was referred to us by SMHI.

5.5.3 Prices

Daily spot prices were provided from Nord Pool. Prices are in SEK per MWh and since the prices were quoted by the hour they have been calculated as a daily average, and adjusted for inflation. Inflation figures were gathered from the Swedish statistical center (SCB 2011b).
The price data was delivered by Nord Pool by letting us gain access to their FTP server which is not publicly available. It is considered very trustworthy since Nord Pool is a reputable company and is subject to regulations and investigations by independent organizations.

5.5.4 Hydrological factors

There are several different ways to measure the available quantity of water and how it can be used in production. We have chosen to use precipitation, snow depth, inflow of water to reservoirs and the actual content in the reservoir. The variables were chosen both based on previous research and own reasoning.
The reservoir content is how much water measured in GWh that is kept in the reservoirs every day. Data was gathered from Nord Pool where it was stated as a weekly average. To be able to use it in the analysis it was converted to a daily average.
From Nord Pool data on inflow, was also gathered. The inflow is the amount of water that runs to the reservoirs and hydropower plants and is measured in GWh. As with reservoir content a weekly average was converted in to a daily average.
SMHI provided data on precipitation and snow depth from their measuring stations and is measured in centimeters. Data from five different stations was chosen due to their geographical location, close to clusters of hydro power plants. The stations used were; Arjeplog A, Kvikkjokk-Årrenjarka, Gäddede, Hemavan and Storlien-Visjövalen.

The validity of the data is considered high since it is provided by SMHI and Nord Pool however the choice of measuring stations can be debated. Only five stations were relevant for the purpose of the investigation and probably do not capture the total effect of precipitation and snow depth.

5.5.5 Quantity

The data regarding quantity of electricity produced and consumed in Sweden was gathered from Nord Pool and is measured in MWh. The data was by the hour and a daily average was calculated. When estimating supply and demand curves only one quantity can be observed to find the equilibrium, supply and demand theory assumes that there is no import or export and that all produced quantity is consumed. Hence, the smallest quantity out of produced and consumed quantity has been chosen for every day and used in the analysis since this quantity is where the supply and demand intersects. This may not be the correct quantity for the purpose of the analysis since the actual supply and demand is not always at the intersection point. The fact remains that the electricity is transferred across countries and it is necessary only have one quantity in the analysis for investigating the Swedish market by itself.

The data on electricity produced and consumed is considered valid since it was provided by Nord Pool but as discussed above the use of a single quantity has some disadvantages since it does not at all times include the total quantity produced or consumed. It was however a necessary simplification in order to conduct a supply and demand analysis.

6 Results and analysis

In this chapter the results from the regressions are presented and interpreted. Short comments follow the results.

6.1 Supply

In the first step of the analysis the result of the first stage in the 2SLS is presented and interpreted. The results for the supply equation are shown below:

Table 1. First stage regression

Year	R-squared	P-value temp
1996	0.671	0.000
1997	0.791	0.076
1998	0.770	0.004
1999	0.760	0.000
2000	0.621	0.000
2001	0.445	0.001
2002	0.925	0.002
2003	0.801	0.000
2004	0.430	0.011
2005	0.715	0.000
2006	0.788	0.005
2007	0.836	0.000
2008	0.752	0.001
2009	0.390	0.000

As can be seen in the table the instrument temp is significant at the 5 percent level in every year except in 1997. R-squared is relatively high for every year which shows that temperature explains changes price in a good way and is a functioning instrument.

The second regression in the 2SLS shows the price elasticity of supply and the results are presented below:

Table 2. Second stage regression

Year	P-value price	Elasticity
1996	0.000	1.274
1997	0.045	2.136
1998	0.001	1.391
1999	0.000	0.966
2000	0.000	0.488
2001	0.000	0.597
2002	0.001	0.748
2003	0.000	0.545
2004	0.005	1.431
2005	0.000	0.734
2006	0.005	1.166
2007	0.000	0.619
2008	0.000	0.903
2009	0.000	0.738

The variable price is significant at the 5 percent level for every year. The R-squared is not relevant at the second stage of a 2SLS regression since we are trying to estimate the actual model using instruments but the actual values are used to compute the R-squared[1]. What is of importance is that the estimated variable of interest has significance in the model. The elasticity is positive every year which means that after the other variables have been controlled for an increase in price leads to an increase in supply as well. Some years the elasticity is above 1 which means that the supply is elastic i.e. if price increases by 1 percent the supply increases by more than 1 percent. This is in line with the electricity producers' profit maximizing approach where they want to produce more when the price is high. No observable trend in the elasticity can be seen and the elasticity varies from year to year.

[1]More information on this matter can be found at http://www.stata.com/support/faqs/stat/2sls.html (2011-05-10)

6.2 Demand

In the first step of the analysis the result of the first stage in the 2SLS is presented and interpreted. The results for the demand equation are shown below:

Table 3. First stage regression

Year	R-squared	P-value content	P-value inflow	F-statistics
1996	0.670	0.008	0.000	0.000
1997	0.826	0.162	0.000	0.000
1998	0.801	0.928	0.000	0.000
1999	0.799	0.152	0.310	0.297
2000	0.699	0.083	0.000	0.000
2001	0.556	0.319	0.003	0.008
2002	0.942	0.576	0.006	0.021
2003	0.786	0,000	0.000	0.000
2004	0.557	0.232	0.001	0.001
2005	0.782	0.129	0.419	0.126
2006	0.828	0.063	0.000	0.000
2007	0.880	0,000	0.036	0.000
2008	0.797	0,000	0.000	0.000
2009	0.474	0.071	0.000	0.000

In the demand model two instruments were used for price and for every year, except 1999 and 2005, at least one of the variables is significant at the 5 percent level. The F-statistics shows if the variables are jointly significant and they are jointly significant at the 5 percent level for every year except 1999 and 2005. The R-squared is at a satisfactory level for all years i.e. price is instrumented accurately.

The second regression in the 2SLS shows the price elasticity of demand and the results are presented below:

Table 4. Second stage regression

Year	P-valueprice	Elasticity
1996	0.816	0.020
1997	0.013	-0.164
1998	0.898	0.006
1999	0.081	0.924
2000	0.949	-0.003
2001	0.006	0.317
2002	0.035	-0.161
2003	0.006	-0.133
2004	0.002	-0.751
2005	0.445	-0.247
2006	0.201	-0.110
2007	0.025	-0.291
2008	0.178	0.031
2009	0.043	0.113

As mentioned above the R-squared is not relevant in the second stage of a 2SLS regression. In the demand estimation the significance varies a lot from year to year and only in year 1997, 2001, 2002, 2003, 2004, 2007 and 2009 is the elasticity significant at the 5 percent level. This implies that the price is not always relevant for the quantity of electricity demanded. One explanation could be that for those years temperature solely drives consumption and the price does not affect consumer's electricity usage. For the years where price is significant the elasticity is between -0,75 and 0,3. The elasticities varies between being positive and negative and the average elasticity for those years is -0,15 which can be said is close to zero. This implies that price has no effect on consumption when other variables such as temperature have been controlled for.

7 Concluding discussion

In this chapter the underlying reasons of the result are discussed. Additionally the possible implications and usefulness of the results are discussed.

7.1 Supply curve

The results show that the price elasticity for supply was positive in the studied years, which is in line with Halseth's research (1999) that there is an incentive for producers to limit their production when price is low in order to increase it. As water can be stored in the water reservoirs it is possible for hydro power plant owners to produce more when price increases as the positive elasticity of supply shows. Energimarknadsinspektionen (2010:21) explains that there are many factors that inhibit effective competition among suppliers where one is the co-ownership of power plants. This is one of the reasons why the electricity market is not perfectly competitive, since companies can set their quantities dependent on each other instead of striving to supply electricity at a lower price to gain market share.

7.2 Demand curve

The results for the demand of electricity shows that elasticity varies between being positive and negative which can be interpreted as the elasticity for demand being close to zero. These results have several plausible explanations. The results are similar to Lijesen (2006) that investigates real-time price elasticity on demand for peak periods in the Netherlands using a Two Stage Least Square analysis. The estimations showed a price elasticity of -0.0014 for the linear specification and -0.0043 for the loglinear specification. He argues that the low price elasticity can be explained by the fact that most consumers do not observe the spot prices. The total quantity demanded is compiled of both the demand from industries and the demand from private households. Industry demand is fairly constant during the year as electricity is often an essential part of daily production. Some companies with a large demand for electricity negotiate deals to be supplied electricity at a predetermined rate, which would be manifested as zero price elasticity in our analysis. In the case of private households Damsgaard (2003) shows that only a few type of households tries to limit their energy consumption and those households does not seem to be enough to influence the outcome of our analysis. As with industries, electricity is such a necessary good with few or no substitutes so that even a price increase does not reduce demand.

Also the model used in this report only measures the short-term price elasticity and a yearly average. It could be that industries and private consumers react to price changes in the long run by negotiating flat rates, switch from electricity heating during the winter to other forms of heating, use more energy saving apparel etc. Additionally only an average is estimated and elasticity could vary between different intervals of the demand curve. The model showed many years where price was not significant as an estimator of quantity and that could depend on the use of poor instruments. It could also result from price simply not affecting quantity when other variables such as temperature have been controlled for.

7.3 Implications

The implication of these results, if they are true, is that consumers of electricity are either somewhat indifferent to price changes, or more likely, have limited opportunities to change their electricity consumption. This means that the suppliers by different strategies such as neglecting to invest in expanded production capacity (Tangerås and Fridolfsson 2009) can keep prices at high levels. The information provided in this thesis should inspire a more active government involvement in the electricity market and more active work to inform consumers on how they can affect the electricity prices, conserve electricity when prices are high and find appropriate substitutes for electrical heating. It also shows that a government environmental policy with the aim of reducing electricity consumption by increasing its price with taxes may not be effective due to the lack of demand price elasticity.

8 Conclusions and future research

The aim of the thesis was to estimate the price elasticity of supply and demand for electricity in Sweden. Data was collected from publicly available sources and from Nord Pool. Through two Multiple Regression Models in a Simultaneous Equation Model yearly price elasticity was calculated for the years 1996-2009. Instrument for price was used, temperature in the supply equation and content and inflow in the demand equation. Temperature was significant for all years and content and inflow were jointly significant for all years except 1999 and 2005.

The results showed that the price elasticity of supply is positive which could result from producers adjusting their production according to price, limiting production when price is low and increasing production when price is high. The price elasticity of demand is close to zero, which may be explained by electricity being an essential good with low price elasticity in the short run.

8.1 Future research

In order to more accurately calculate the price elasticity of demand a more elaborate dataset needs to be used, containing information on the final price the end consumers pay. This includes the impact of fixed and variable electricity contracts for the end price of consumers as well as taxes and fees. Also the market might have to be segmented in the investigation in order to analyze industry and private households separately.

This report has only estimated the short-run elasticity. We believe that more research needs to be performed in order to illuminate the long-term price elasticity of electricity. Particularly households that use electricity for heating have options to reduce their electricity consumption by changing their mode of heating. However such changes require considerate investments and are only feasible in the long-term. Obtaining a more accurate price elasticity of demand would be useful in long-term planning of governmental environmental and taxation policy.

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