BACHELOR THESIS

Quota obligation and tradable green certificate scheme

Effects on end user price and renewable electricity production in Sweden

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ABSTRACT

This thesis empirically investigates the impacts that the implementation of tradable certificate scheme along with the quota obligation has had on the end user price of electricity in Sweden. It also empirically investigates what effects an increased sized quota obligation has had on the production of renewable electricity in Sweden. The study uses ordinary least square technique (OLS) to test the relationships of interest. Theoretical assumptions are derived mathematically and this is used as a foundation to for the OLS regressions. Conclusions that can be made from this thesis is that an increased (1 %) sized quota obligation will cause the production of renewable electricity to increase (0.44 %). It also shows that the end user price will be positively correlated with the size of the quota obligation.

SAMMANFATTNING

Denna uppsats undersöker empiriskt vilka effekter som införandet av handel med elcertifikat och kvotplikt har haft för slutkonsumentens elpris i Sverige. Uppsatsen undersöker också empiriskt vilka effekter en ökad kvotplikt har haft för produktionen av förnybar el i Sverige. Studien använder ordinary least square (OLS) teknik för att testa sambanden av intresse. Teoretiska antaganden härleds matematiskt och används sedan som en grundpelare för OLS regressionerna. Slutsatser som kan göras utifrån denna uppsatts är att en ökad kvotplikt (1 %) kommer att innebära att produktionen av förnybar el ökar (0.44 %). Studien kommer också att visa att slutanvändarens pris på el är positivt korrelerat med storleken på kvotplikten.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

1.1Background

The environmental problem has for quite some time been high on the European Union's agenda. Decreasing the emissions of greenhouse gas has been one major part in their work for the environment. Since 95 % of the greenhouse gas originates from fossil fuel combustion the European Union has recognized the importance of decreasing the use of fossil fuels. In 2003, as much as 75 % of the total emissions of greenhouse gas were in some way related to the production of energy[1] while the rest came from the transportation sector. This emphasizes the importance of change in the production of electricity that the tradable green certificate system together with the quota obligation is supposed to do (Nielsen & Jeppesen, 2003). As a consequence, the European Union has given each member state directives that they need to support the production of renewable electricity. Quantitative targets of renewable electricity production have been set for each member of the Union. Although the levels of the renewable electricity production is set in quantitative terms from the European Union a great degree of freedom exists for the member nations to decide how to reach those quantitative targets (Ek & Söderholm, 2008a).

The most dominating sources for the production of electricity in Sweden are nuclear- and hydro power. During 2010 those two sources stood for a combined production that amounted to about 76[2] % of the nations measured as the net production which means

[1]Although this number is not likely true for Sweden due to the nation's high capacity from hydro power.
[2]Including large scale hydro power.

the produced quantity after deduction of electricity which the production process uses itself. In contrast, renewable electricity sources, as defined in the green certificate scheme[3], share during the same year was slightly less than 12 % (Statistics Sweden, 2010).

Even if nuclear- and hydro power does not, in a large scale, contribute to emissions of greenhouse gas there are still some problems associated with that kind of electricity production. For example, regarding nuclear power there is no long run solution for the nuclear waste storage. This has also been made clear by the national council for nuclear waste, KASAM, who emphasize the importance on more research on the subject. Further, they argue, that natural disasters such as earthquakes and the unreliability of the human factor might result in devastating consequences not only for the environment but also for the population (SOU 2002:63). After the recent development in Japan it is also a fair assumption that more focus will be shifted towards those types of security issues. Regarding hydro power the first and most obvious disadvantage is that the possibility to expand the capacity is heavily restricted by nature characteristics. Therefore it is not possible, because of nature constraints, to expand the capacity sufficient enough to meet the demanded quantity of electricity. There is, in similarity with nuclear power, also security issues connected to hydro power. Natural disasters can have devastating consequences for hydro power as well, with extreme flooding as a result. Furthermore, the expansion of hydro power will deteriorate the possibility for fishermen as well as worsen the environment for people that live downstream the facility (SOU 2009:42)

In Sweden, the market for electricity has been deregulated since 1996 which means that consumers since then can chose to buy their electricity from any supplier they want. Because of this, product differentiation became increasingly more important for the distributors of electricity as a way to get a larger share of the market. One way to differentiate electricity was done by the Swedish society for nature conservation who started to label electricity that came from renewable sources as green in hope that this would increase the demand for renewable electricity and hence decrease the production of electricity that was harmful for the environment. This action by the Swedish society for

[3] Large scale hydro power is not included in this number since they are not eligible for electricity certificates.

nature conservation combined with the facts that the market was deregulated and the growing importance of product differentiation meant that the consumer now could choose to only buy electricity labeled as green. This way, an opportunity was given to the consumer to be part of a more environmental friendly lifestyle. Not surprisingly, the option of a more environmental friendly lifestyle came at a cost. If the consumer elected this option it meant that she had to pay an extra premium on the electricity bill. Although the premium was not higher than between 0.005-0.1 SEK per KWh very few households in Sweden made an active choice for green labeled electricity (Ek & Söderholm, 2008a).

This lack of demand for renewable electricity forced the Swedish government to take action in order to meet their obligations set by the European Union. In 2002 the Swedish government decided that the need for a higher demand on renewable electricity should be supported by the tradable green certificate system together with a quota obligation for all consumers of electricity[4] (Ek & Söderholm, 2008a). This was implemented in May 2003. The main purpose of the green certificate system was to increase the production of renewable electricity by 17 TWh from the 2002 production level until the end of 2016. This has later been revised and the new target is now to increase renewable electricity production by 25 TWh until 2020 compared with the 2002 level. (2010/742/E).

All producers, approved by the Swedish energy agency, of renewable electricity will for free receive one certificate per MWh produced from the state. This certificate can then be sold on the market. Since all distributors of electricity are obligated to buy a certain amount of certificates based on their total quantity sold times the quota this will create a demand for the certificates. In addition it will also increase the revenue for the producers that receive certificates from the state. Consequently, it will also increase both the incentives of expansion and the production of the electricity that originates from renewable sources (Swedish energy agency, 2010).

Access to electricity is of course of major importance for the society in many ways. It is therefore crucial that Sweden learn to meet the demanded quantity of electricity in such a way that the environment is affected as little as possible. Intuitively a higher quota will

[4]This obligation has since then changed from the consumer to the distributer.

lead to an increased renewable electricity production. In reality this is however not necessary true since the quota is set as a percentage level of total electricity production. This thesis will therefore, empirically, investigate what effects the tradable green certificate scheme has had on the production of renewable electricity and what the consumer costs for this scheme have been. Hypotheses that are made are that an increased sized quota will increase both the end user price of electricity and the production, in absolute numbers, of renewable electricity.

1.2 Purpose

The purpose of this thesis is to examine the affects that the implementation of tradable green certificate scheme along with the quota obligation has had on the production of renewable electricity. I will also try to make an assessment about the effect that the quota obligation has had on the end user price.

1.3 Methodology

To examine the effects the implementation of the tradable green certificate scheme has had on the production of renewable electricity a quantitative approach will be used. Quantitative data is collected mainly from Statistics Sweden and the Swedish energy agency. Regarding the cost for the end user, calculations will be made on the price level of electricity with the tradable green certificate scheme and then this will be compared to what would have been the price had the scheme not been implemented. A theoretical approach, suggested by Amundensen and Nese (2009), will be used as a theoretical frame of reference on how the production and price level will change in relation to the quota.

1.4 Scope and limitations

The thesis will be limited to the time frame between May 2003 and December 2010. The reason for this is because it is the period which the tradable green certificate scheme has been in operation. It is also important to emphasize that it is the produced quantity that is being measured and not the capacity. Since some of the eligible sources for certificates are highly dependent on weather conditions (i.e., wind- and hydro power), there might be a large difference between the capacity and the produced quantity. Consequently, the weather is a factor that might change the result substantially. To make calculations easier some assumptions are made regarding how the market for electricity works. Perfect competition in the market, with many producers, distributers and end users are assumed. Hence all participants treat the price as given by the market.

1.5 Earlier studies

Because of the increasing interest about different approaches to tackle the environmental problems a large number of studies have been on the green certificate trading scheme. Bergek and Jacobsson (2010) examine the *ex-post* performance with the *ex-ante* expectations of the scheme at the Swedish and European Union level. Their conclusions are that the Swedish scheme is effective both in meeting the quantitative targets as well as doing this in a social cost efficient way. They argue that the scheme has been of vital importance for the interest among firms to invest in renewable electricity production, and this has been done in a social cost efficient way. Not everything is positive though. Bergek and Jacobsson (2010) also points at the fact that consumer costs for electricity have been far higher than what was expected. Further they find no empirical support for the expectation that the implementation of the scheme should drive technical progress in the renewable energy sector. Overcompensation of the most cost efficient producers of renewable electricity is also a problem with the scheme according to the authors. The reason for this is because as the quota rises, more and more expensive technology must be taken in production and it is the marginal producer that will set the price of the certificate. This then means that all producers, except the marginal, will make excess profits and the scheme becomes a rent generating machine. This thesis will present the price of the certificates, which will reflect the marginal cost of production for renewable electricity, assuming perfect competition in the market.

Another study made by Agnolucci (2007) emphasizes the importance of political reliability for the tradable green certificate scheme. He argues that uncertainty on the scheme and hence higher investment risk will create a need for a higher risk premium and therefore the expansion of renewable energy capacity will be slow. This is simply because under uncertainty, the risk-reward ratio is not high enough for investments to take place. In his opinion it is therefore of crucial importance that the tradable green certificate scheme is complemented with long term contracts, which lowers the risk involved with investments, for the scheme to be effective. Without a decrease in the risk involved with investment in renewable electricity it is likely that a rise on the quota obligation not will cause new entries to the market. Rather it will only raise the price of the certificates. Since the repayment time for a renewable electricity investment is longer than the 15 years renewable electricity producers are eligible for certificates political uncertainty about the future of certificates is an obstacle that currently is holding expansion of renewable electricity capacity back. Certainly, if the producers of renewable electricity would be confident in making a profit, additional capacity would without any reasonable doubt enter the market. As mentioned earlier, another factor that strongly contributes to the risk involved in investments in production of renewable electricity is the fluctuations in production, which is mainly due to weather conditions (Lemming, 2003).

Söderholm and Michanek (2006) make it very clear that the expansion of renewable energy production is held back thanks to bureaucratic behavior in the permit process for the expansion of the renewable electricity sources. Furthermore, the Swedish energy agency reported, in 2007, that the supply of wind turbines was very limited and as a consequence held back the expansion of capacity for wind power (Swedish energy agency, 2007).

Amundsen and Nese (2009) ask the question about what can be expected of the implementation of a tradable green certificate scheme. Their conclusions are, among others, that the size of the quota obligation is not a good policy for stimulating the renewable energy production. They argue that an increase of the obligation not necessarily will increase the total production from renewable sources. Rather it will guarantee that the production of electricity originating from any other source then the sources eligible for certificates (i.e., “black” production) will decrease. Because of this, the quota as a policy instrument will only guarantee that the share of renewable electricity will increase. A tradable green certificate scheme might because of this not be the best instrument to use if the objective is to increase the production of renewable electricity and not only its share of total production (Amundsen & Nese, 2009). This relationship will be empirically tested in this thesis.

As more and more new production from renewable electricity producers will be required to meet the quota obligations set by the Swedish government, assuming that total production is unchanged, alternative methods must be used. One method of increasing this production is to invest in offshore wind power farms. Söderholm and Pettersson (2011) claims that the incentives for investing in this, in the long run very promising source of renewable electricity production, is too weak. A stronger financial support to offshore wind projects in Sweden is necessary to increase the interest for investors to invest in offshore wind farms. They argue that a stronger financial support would be a vital part of the objective to meet the increase in renewable energy production (Söderholm & Pettersson, 2011).

It is also of major importance for a success of a tradable green certificate and quota obligation policy that the scheme itself has support from the population. Ek and Söderholm (2008b) indirect gives support to the tradable green certificate scheme since they find the willingness to pay for green electricity to be higher when consumers participation is mandatory compared to, as was the case in Sweden between 1996-2002, when the participation is voluntarily (Ek & Söderholm, 2008b). A conclusion that can be made by their study is therefore that is more likely that a tradable green certificate system will gain support from the public since everyone in the country contribute on a mandatory basis.

All those studies mentioned above have been a point of reference for this thesis and a foundation stone in the model specification.

1.5 Outline

The thesis is divided into five chapters. *Chapter two* will present how the tradable green certificate system along with the quota obligation works in practice. It will also present the expectations that the Swedish government had on the scheme. *Chapter three* will discuss the theory behind the supply and demand and what effects the implementation, and an increased quota obligation will have on the production of renewable electricity from a theoretical approach. *Chapter four* will present the results of the study and comparisons will be made between empirical and theoretical results. *Chapter five* will end the thesis with a discussion of the tradable green certificate and quota obligation policy with the empirical results as a point of reference.

Chapter 2

TRADABLE GREEN CERTIFICATES SCHEME

2.1 Eligible producers

To be able to receive electricity certificates the producer must be approved by the Swedish energy agency. The approval is conditional on what source the producer uses for its production of electricity. Each plant taken in operation after 2003 is guaranteed to receive certificates 15 years but no longer then until the end of 2035. The producers of renewable electricity that was already in operation when the reform took place in 2003 are eligible to receive certificates up until 2012 or 2014 depending on if the producer received support from the government while building the plant in the first place. To get an approval, one of the following conditions must be fulfilled (Swedish energy agency, 2010):

The electricity must be produced using:

(1) Wind.
(2) Sun.
(3) Wave.
(4) Biofuels.
(5) Peat
(6) Small scale hydro.

Every approved producer will for free get one certificate per MWh produced. This can later be sold on the market and hence create extra revenue for the producers of renewable electricity. In practice this means that the revenue a producer of renewable electricity receives is calculated by adding the market price for electricity (i.e., the Nord Pool spot price) and the certificate price. This is supposed to increase the incentives to invest in renewable electricity production (Swedish energy agency, 2010). Holders of certificates can, if they choose to, bank the certificates and sell them at any time they want (Bergek & Jacobsson, 2010). This option is important for the risk involved in investing in renewable electricity capacity. For example, Lemming (2003) reports that the price of certificates are negatively correlated to the wind conditions. For a wind power owner this is positive because in a calm year when production is low, the price on the certificate will be higher and the opposite will be true in a windy year. Hence, the relatively high volatility in the price of the certificates, plotted in figure 1, might actually reduce the risk involved in investing in renewable electricity production. The option to bank certificates is thus importance because it means that a producer can save certificates and sell them a later time when the price is higher thanks to a decreased supply. This makes it possible to get a rate of return on the certificates that are higher than what would have been possible otherwise (Lemming, 2003).

In 2010 the sources contribution to total renewable electricity generation came almost only from wind, biofuels and small scale hydro as can be seen from figure 2 below (Svenska kraftnät, 2010).

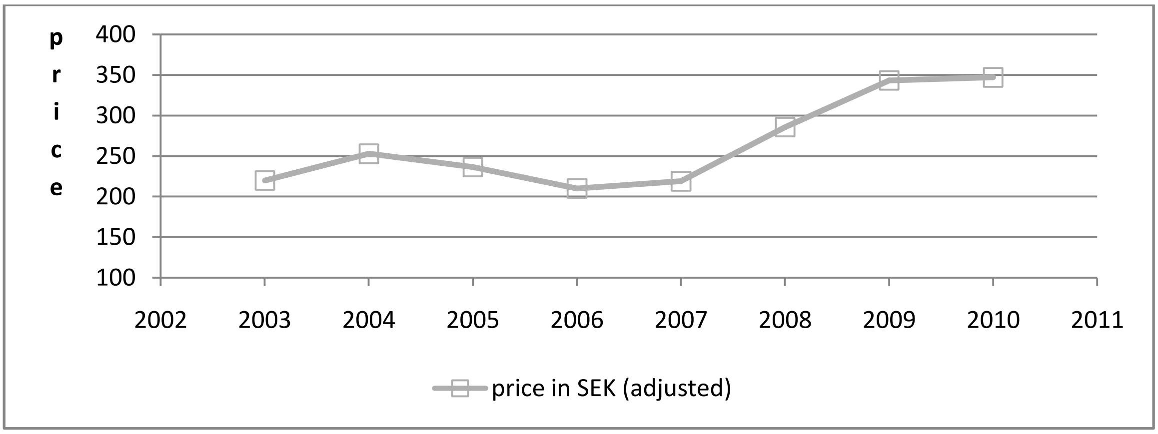

Figure 1. Electricity certificates prices, adjusted for inflation in Sweden (Index = 1996).

Sources: Svenska kraftnät (2010) & Statistics Sweden (2010)

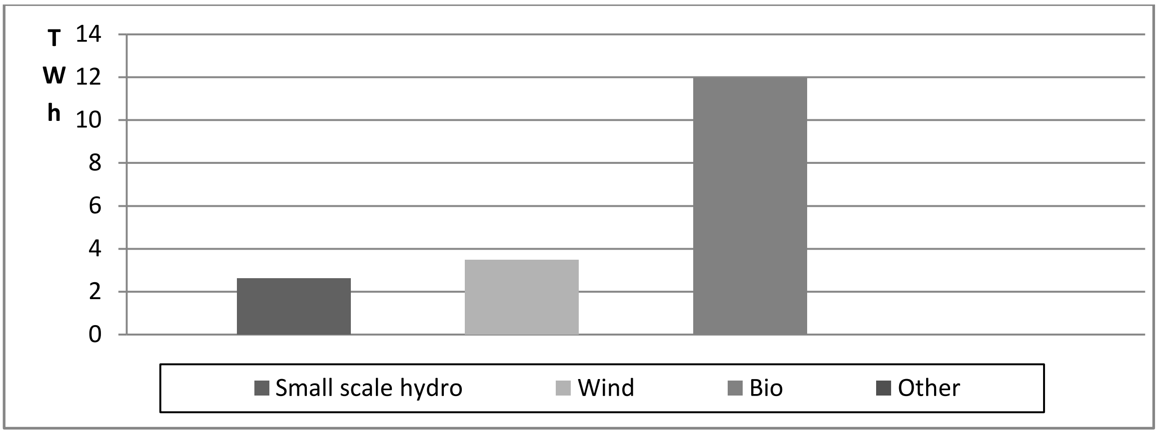

Figure 2. Renewable sources contribution to total renewable production in 2010.

Source: Svenska kraftnät (2010).

2.2 Quota obligation

To create a demand for the certificates, each distributer of electricity is by law obligated to hold a certain amount of certificates depending on their total quantity sold and the current quota level. This obligation was originally made for the consumers, but in 2006 this changed and since then the distributers of electricity are the ones obligated to hold certificates. The level of the quota obligation, which changes every year (see table 1) is set by the Swedish government and it is supposed to correspond to a certain level of renewable electricity production. If a distributor fails to meet the quota obligation they must pay 150 % of the average certificate price for the previous year for the numbers of certificates they do not hold. The two first years this penalty was limited to 175 SEK in 2003 and 240 SEK in 2004. The reason behind this cap was to protect the consumers of too high price on electricity. This cap in certificate prices was removed in 2006 because it was price setting and therefore undermined the effectiveness in the certificates market. Since this cap was removed demand for certificates is inelastic because buying certificates of prices below 150 % of the average yearly price will result in higher profit for distributers that are short on certificates. This is simply because the price they will pay if they fail to meet their obligation (150 % of year average) will be higher than any prices below 150 % of the yearly average. (Swedish energy agency, 2010; Bergek & Jacobsson, 2010).

Table 1. Quota obligation 2003-2018 in Sweden.

Year	Quota	Year	Quota
2003	0,074	2011	0,179
2004	0,081	2012	0,135
2005	0,104	2013	0,142
2006	0,126	2014	0,143
2007	0,151	2015	0,144
2008	0,163	2016	0,152
2009	0,170	2017	0,168
2010	0,179	2018	0,181

Source: Swedish energy agency 2010.

Because of the design of the tradable green certificate system the demand for certificates each year can be assumed to be the quota obligated production times the size of the quota obligated production (Amundsen & Nese, 2009). The decreased quota obligation between year 2011 and 2012 depends on the fact that some producers, initially included to receive certificates, will lose this benefit in 2012 (Swedish energy agency, 2010).

There are some exceptions on the quota obligation. Electricity intensive industry is not included in the system. The reason for this exclusion is that the competiveness of Swedish industry is not supposed to decrease thanks to the higher production costs including them in the system would result in (Swedish energy agency, 2010). Approximately one third of the total use of electricity is classified as electricity intensive industry and hence excluded from the tradable green certificate and quota obligation policy (Bergek & Jacobsson, 2010).

2.3 Expectations[5]

The implementation of the tradable green certificate system scheme together with the quota obligation system was one important policy for Sweden to meet the required reduction of greenhouse gas set by the European Union (Bergek & Jacobsson, 2010). In quantitative terms, an accumulated increase of renewable electricity production of 17 TWh from 2002 level up to 2016 was the target. This has later been revised to 25 TWh

[5] All translations from SOU 2001:77 is done by Bergek & Jacobsson (2010)

accumulated production until 2020 (Swedish energy agency, 2010). An official government report states, among other things, three major expectations on the implementation of the tradable green certificate system. The report clearly states that those three expectations are substantially increased production of renewable electricity. Further this increase was to be done in a cost effective way and at last it should increase the competiveness among producers of renewable electricity and hence drive technical development in the renewable electricity production industry.

Regarding the *first* expectation about the increased production of renewable electricity, the government official report states:

> *"The certificates are, thus, a means which primarily relate to the goal of increasing the share of electricity from renewable energy sources. The objective of this goal is, in the long run, to obtain a sustainable energy system built on renewable energy sources. In Sweden, such a development is necessary in order to manage the transition of the energy system in connection with the phasing out of nuclear power"* (SOU, 2001:77, p. 108).

The *second* expectation about cost effectiveness was in the same directive expressed as:

> *"An efficient promotion of electricity from renewable energy sources implies … that the total cost … shall be as low as possible. An efficient solution that is adjusted to the conditions of the market is to let the quota rise gradually. Investments with low marginal costs will be included first and only thereafter will investments with a higher marginal cost be included"* (SOU, 2001:77, p. 125).

Bergek and Jacobsson (2010) also reports that the major weight given to cost minimization in large was due to the fact that the Swedish government realized the importance of keeping the consumer costs down in order for the system to gain acceptance among the public. Further they argue that cost minimization was very important to keep Swedish industry, not excluded from the quota obligation, competitive on an international as well as domestic level (Bergek & Jacobsson, 2010).

Figure 3 below shows how the supply of the certificates was expected to look like. When different types of production are taken in operation in an order corresponding to the production with least cost first and highest costs last, the production of renewable electricity will be done in a cost effective manner. Because of the design of the policy this was also seen as the most likely scenario. This means that as the quota obligation becomes bigger (see table 1) the marginal producer of renewable electricity will be the price setting firm for the certificates. Since this supply curve is assumed to have a positive slope, an increasing certificate price is to be expected as the quota rises (SOU, 2001:77).

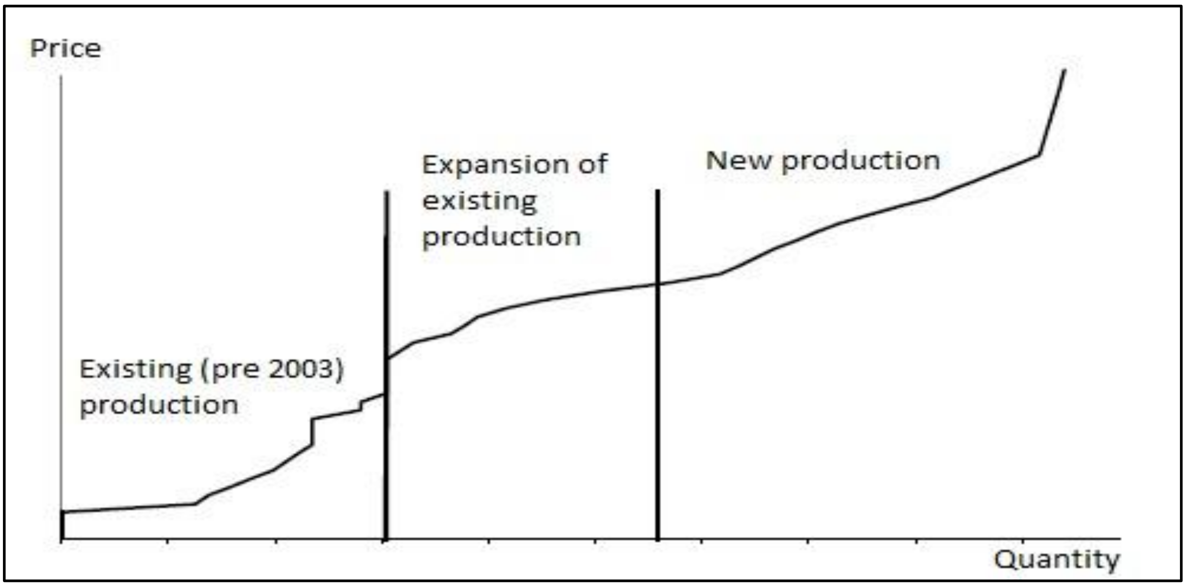

Figure 3. The expected supply curve for certificates.

Source: SOU, 2001:77. Own translation.

The last and *third* expectation about the increased competition and the drive of technical development can be seen from the follow quote:

> *"The transition to market based solutions to promote power from renewable energy sources means that conditions are created for an effective competition between different forms of power from renewable energy sources. An effective competition leads to cost efficiency and to the development of new technical solutions"* (SOU, 2001:77 p. 104).

In accordance with economic theory a technical development in the renewable energy production industry would mean an outward shift in the supply curve which in turn, *ceteris paribus,* would lower the price of the certificates and hence the electricity cost for the consumer. This decreased cost for renewable electricity production would reduce the need of certificate revenue for the producers of renewable electricity. If the technical progress, in the long run, is big enough in the renewable electricity producing industry, the certificates will not be necessary at all since the renewable production then can be run profitable without any interference from the government (SOU, 2001:77).

To summarize it is hence fair to assume that an increasing level of the quota obligation will cause the certificate price to increase (see figure 3) as more and more expensive production must be taken into operation. In contrast to the findings of Bergek & Jacobsson (2010) this should strengthen the incentives of technological development. If current renewable producers knew this, which is assumed that they do, money spent on research and development could, if successful, create even higher profits then what they currently produce. It is therefore *ex ante* likely that the green tradable certificate scheme will drive technical development through profit incentives since a fair assumption is that the certificate price, and hence the revenue for renewable electricity producers, is going to increase. And this increase will, of course, be bigger in a more technical developed, and hence more cost efficient, facility.

Chapter 3

THEORY AND MODEL

3.1 A mathematical approach

To be able to empirical test a relation, for example what factors that affects the price of the certificates, a theoretical starting point must be assumed. Amundsen and Nese (2009) present a model in which the price on the certificates as well as the effects of a change in the quota obligation size can be interpreted. For calculation convenience perfect completion is assumed, meaning a lot of suppliers in the production of renewable electricity (i.e., "green" electricity) as well as in the production of electricity not eligible to be classified as renewable production (i.e., "black" electricity). Furthermore, the perfect competition assumption also implies that many distributers and many consumers are assumed as well as the fact that they all take the price as given by the market. The last assumption being made is that the distribution of electricity is costless (Amundsen & Nese, 2009).

The model outline is based on Amundsen and Neses (2009) work with some minor adjustment made. I have, for instance, included some calculations that the original authors left out because I believe that this makes the mathematical section easier to grasp for a reader without a deeper knowledge of mathematics. Furthermore I have included some comments on the results given by this mathematical approach that the original authors left out for the same reason as mentioned above.

Table 2 present the definitions of used variables.

Table 2. Definition of variables used.

Variable	Definition
p	End-user (i.e., consumer) price of electricity (excluding taxes)
s	Price of the tradable green certificates
q	Wholesale (i.e., Nord Pool spot price) price of electricity
x	Total consumption of electricity (excluding electricity intense industry)
y	Production of "black" electricity
z	Production of "green" electricity
$\boldsymbol{\alpha}$	Size of the quota obligation as a percent of *x.*
$\boldsymbol{g^d}$	Demand for the certificates
$\boldsymbol{g^s}$	Supply of the certificates
p(x)	Inverse demand function of electricity assuming that $\partial p(x)/\partial x < 0$[6]
c(y)	Cost function for production of "black" electricity.
h(z)	Cost function for production of "green" electricity.
$\boldsymbol{\pi}$	Profit function

It is assumed that firms seeks to maximize profits. Since two outputs are considered the profit function can be derived either over the production of "black" electricity or over the production of "green" electricity. Further assumptions are that $\partial c/\partial y > 0$ and that $\partial^2 c/\partial y^2 \geq 0$ and that $\partial h/\partial z > 0$ and that $\partial^2 h/\partial z^2 \geq 0$[7].

$$max(y,z) = qy + [q+s]z - c(y) - h(z) \tag{1}$$

The first order conditions for this expression will be

$$\frac{\partial \pi(y,z)}{\partial y} = q - \frac{\partial c(y)}{\partial y} \equiv 0 \rightarrow MR_{black} = MC_{black} \tag{2}$$

$$\frac{\partial \pi(y,z)}{\partial z} = q + s - \frac{\partial h(z)}{\partial z} \equiv 0 \rightarrow MR_{green} = MC_{green} \tag{3}$$

So far the results are in line with economic theory which states that a profit maximizing firm should produce a quantity that makes the marginal cost (MC) equal to the marginal revenue (MR) (Nicholson & Snyder, 2008). In this case this implies that a renewable electricity producer should produce up to the point where its marginal cost equals the

[6] Meaning that *x* is a normal good.
[7] Meaning that the marginal cost of producing "black" and "green" electricity is positive and increasing or constant.

wholesale price plus the certificate price. For a “black” electricity producer it implies that they should produce up to the point where the wholesale price equals the marginal cost of production. Given that the first order conditions holds and that electricity distribution is costless, the equilibrium price in the market is thus given by:

$$p = q + \alpha s \tag{4}$$

Equation, (4), states that the consumer price of electricity must equal the wholesale price (i.e., the Nord Pool spot price) plus a share, corresponding to the size of the current quota obligation times the price of the tradable green certificate. This is also in line with economic theory, if perfect competition is assumed. For instance, if $p > q + as$ abnormal profits would be made by the distributors and a foundation stone of the perfect competition conditions would be violated (Nicholson & Snyder 2008). Further, the demand and supply for the tradable green certificates must be characterized by:

$$g^d = \alpha x \; and \; g^s = z \tag{5}$$

The demand of tradable green certificates is thus simply the quota level times the total consumption (i.e., the distributers sold quantity) and the supply is total “green” electricity produced. With the calculations made so far we can now establish what must be the equilibrium in the markets, the tradable green certificate market and the electricity market. Prices and quantities in equilibrium will be denoted by a star symbol.

$$p(x^*) = q^* + \alpha s^* \tag{6}$$

$$x^* = y^* + z^* = \frac{z^*}{\alpha} \tag{7}$$

$$q^* = \frac{\partial c(y^*)}{\partial y} \tag{8}$$

$$q^* + s^* = \frac{\partial h(z^*)}{\partial z} \tag{9}$$

Note from (7) that:

$$x^* = \frac{z^*}{\alpha} \rightarrow \boxed{z^* = \alpha x^*}\ since\ y^* = x^* - z^* \rightarrow \boxed{y^* = x^*(1-\alpha)} \tag{10}$$

And note from (8) and (9) that:

$$s^* = \frac{\partial h(z^*)}{\partial z} - \frac{\partial c(y^*)}{\partial y} \tag{11}$$

This means that the certificate price should, in equilibrium, exactly equal the vertical difference of marginal costs for "black" and the marginal "green" electricity producer.

This tells us exactly what we would expect from the demand function of tradable green certificates, namely that demand must equal supply for equilibrium to prevail. In this case the production of renewable electricity is equal to the demanded quantity (i.e., αx^*). It is also expected that total consumption of electricity, not originating from a renewable source (i.e., "black" consumption), must be equal to the total production minus the production of "green" electricity (i.e., $y^* = x^*(1-a)$. To find the consumers price of electricity in equilibrium, equation (7), (8) and (9) are substituted in equation (6):

$$p(x^*) = \frac{\partial c(y^*)}{\partial y} + \alpha \left[\frac{\partial h(z^*)}{\partial z} - \frac{\partial c(y^*)}{\partial y} \right] \tag{12}$$

$$\rightarrow p(x^*) = (1-a)\frac{\partial c(y^*)}{\partial y} + a\frac{\partial h(z^*)}{\partial z} \tag{13}$$

Hence, (13) shows that the inverse demand function for electricity is a combination of the marginal costs of the different types of production, "green" and "black". If we assume that the marginal cost for production of both "green" and "black" electricity is increasing this would make it clear that an increase in a would result in an undetermined result of the price. The reasons for this are that while an increase in the quota obligation (a) would increase the "green" electricity marginal cost it would also decrease the production of "black" electricity, assuming total consumption is unchanged, and hence the marginal cost for "black" production would decrease. The effect on the end user price will therefore depend on which of those two effects that is bigger. If the marginal cost for "black" electricity would be constant, the price would certainly go up, again assuming that total consumption (*x*) is unchanged.

To find out what affect an increase in the quota obligation would have on the production of green electricity a mathematical approach is to take the partial derivative of *z* with respect to a. If this derivative is be positive it would imply that an increased level of the quota obligation would result in an increased production of renewable electricity and vice versa if the derivative came out negative. This can be done taking the implicit derivate of (11). Based on Amundsen and Nese (2009) this implicit derivative can be expressed as:

$$\frac{\partial z}{\partial \alpha} = \frac{\overbrace{\alpha s}^{+} + \overbrace{x}^{+}\,[\overbrace{\partial p/\partial x}^{-} - \overbrace{(1-a)}^{+}\overbrace{(\partial^2 c/\partial y^2)}^{+\,or\,0}]}{D} \tag{14}$$

Where

$$D = \left[\overbrace{\frac{\partial p}{\partial x}}^{-} - \overbrace{(1-a)^2}^{+}\overbrace{\frac{\partial^2 c}{\partial y^2}}^{+\,or\,0} - \overbrace{\alpha^2 \frac{\partial^2 h}{\partial z^2}}^{+}\right] \tag{15}$$

The denominator in this expression will be negative because $\partial p/\partial x$ is negative, $(1-a)^2 \frac{\partial^2 c}{\partial y^2}$ and $\alpha^2 \frac{\partial^2 h}{\partial z^2}$ will be positive or zero[8] and hence the total expression will be negative. The numerator will be indeterminate because the left hand side, αs, will for sure be positive while the rest of the numerator for sure will be negative and hence no conclusion can be made. It is therefore not possible to say anything about what will happen to the production of "green" electricity as the quota rises unless the current level

[8]Given that the marginal cost is constant.

is 0, in which case the derivative will come out positive. The effect on "green" electricity production will therefore be empirically tested so equation 14 can be defined. The effect on production of "black" electricity with respect to the quota will be:

$$\frac{\partial y}{\partial \alpha} = \frac{\overbrace{(1-a)s}^{+} + \overbrace{x[a(\partial^2 h/\partial z^2)}^{+} - \overbrace{(\partial p/\partial x)}^{-}]}{D} \tag{16}$$

Inspection of the signs shows that the numerator is positive while the denominator is negative. An increase in a would hence reduce the production of "black" electricity. And exactly as discussed earlier in this section, assuming increasing marginal cost for black electricity production, this increase in a will reduce the marginal cost of black electricity[9]. What also is interesting is to see how the total production of electricity will change as the quota obligation rises. The partial derivative of *x* with respect to *a* results in:

$$\frac{\partial x}{\partial \alpha} = \frac{\overbrace{s + x[a(\partial^2 h/\partial z^2)}^{+} - \overbrace{(1-a)(\partial^2 c/\partial y^2)}^{+\ or\ 0}}{D} \tag{17}$$

As before, the denominator is negative. The numerator is indeterminate but if marginal cost for production of "black" electricity I assumed to be constant, this derivative will come out as negative.

To conclude, an increased sized quota obligation will increase the share of the "green" electricity production but it will not for certain increase the "green" electricity production in absolute terms. The reason behind this is that "black" electricity production will decrease and hence an unchanged, or even decreased, production of "green" electricity might still be a larger share of total production.

[9]Ceteris paribus, the spot price on Nord Pool will decrease.

3.2 Model specification

Since the affect that an increased quota level will have on the production of renewable electricity theoretically is undetermined we need to empirically determine its sign. Thus, a production function for renewable electricity is specified and an inverse demand function is specified to see the quota effect on the end user price level. Ordinary least square (OLS) technique will be used to estimate the quota effect on the end user electricity price. This technique will minimize the residuals (errors) and give a linear relationship between the dependent variable and the independent variables. Under the perfect competition assumption, the marginal cost for "black" electricity production is equal to the wholesale price while the marginal cost of production for "green" electricity is the wholesale price plus the certificate price.

To see what effects the quota, which has been increasing since 2003, has had on the production of renewable electricity OLS will also be used. In this case the regression will be more problematic. There are several reasons for this. First of all, the current production of renewable electricity depends to a great extent on climate circumstances, for which I do not have data. Secondly, the current capacity, and hence production, will in a very large scale depend on earlier expectations regarding current profits which are very hard to measure. The reason for this is that once the investment decision has been made, there are several years of construction and permit procedures that must be done before the investment starts to produce electricity and create revenue. Consequently this then implies that the current wholesale- and certificate price will have little effect on the production since production factors to a great extent is decided by factors that cannot be controlled for. Keeping those problems in mind I will assume that investor expectations are that the certificate price will increase as the quota level increase. And since the quota level is known beforehand, pretty good prognosis regarding the price of the certificates should be possible to make, hence my hypothesis regarding the certificate prices will be that the current production do depend on the current price of the certificates.

Because of the problems involved (mainly weather conditions) with the regression I will use data collected on the production, which will be assumed to on average be some constant[10] times the full capacity, and plot that against the quota level. This assumption is made because a year with less production says nothing about the current capacity. The capacity might well have increased while the production that year has decreased thanks to for example weather conditions.

If the regression shows that there is a positive relationship between the size of the quota and the production of renewable electricity, then the conclusion can be made that $\partial z/\partial \alpha > 0$.

This would then imply that an increase in the size of the quota will increase the production of "green" electricity, not only as a share of total production, but as an absolute value increase. I will use a logarithmic function to make interpretation of the coefficients easier, since they by doing this will be elasticities. The main purpose of making this regression is to see what sign the coefficient of the quota level is going to take (i.e., sign of β_2 in (18)). If the sign comes out as positive, it is evident that an increased sized quota will increase the renewable electricity production (i.e., $\partial z/\partial \alpha > 0$). The function I will use to estimate the renewable production will, after transformation from logarithmic to log-linear, look like this:

$$LN(RP) = \beta_1 + \beta_2 LN(K) + \beta_3 LN(CP) + \beta_4 LN(TOT) + \beta_5 SEASON \qquad (18)$$

Where $LN(RP)$ is the logarithm of total renewable electricity production, $LN(K)$ is the logarithm of the quota, $LN(CP)$ is the logarithm of the certificate price and LN(TOT) is the logarithm of total electricity consumption. $SEASON$ is a dummy variable included to control for seasonal differences. This dummy is set to zero if it is May, June, July or August and otherwise its one. There is also another reason for including this dummy variable. With the assumption that demand for electricity is higher on the cold time of the year, a statistically significant dummy variable would indicate that at least some of the

[10] $0 < constant < 1$

renewable production sources actually can choose increase their production in the short run.

Like Amundsen and Nese (2009) the assumption that the end user price of electricity depends on the wholesale price, the certificate price and the current quota level will be made. If the coefficient of the quota comes out as positive, it can be stated that an increase in the quota level will increase the end user price of electricity.

i.e.,

$$\Delta p = (1-a)\frac{\partial c(y^*)}{\partial y} + a\frac{\partial h(z^*)}{\partial z} > 0 \tag{19}$$

To make the coefficients easier to interpret a logarithmic function will be used. By doing this the coefficients will, as mentioned, be elasticities. Again, the main purpose is to see what sign the coefficient of the quota level is going to take (i.e., sign of β_3 in (20)). If the sign comes out as positive, it is evident that an increased sized quota will increase the end user price positively. To be able to run OLS regression on the function it must be made log-linear. The transformed function will look like this:

$$LN(PRICE) = \beta_1 + \beta_2 LNP(WHOLESALE) + \beta_3 LN(K) + \beta_4 LN(CP) \tag{20}$$

Where $LN(PRICE)$ is the logarithmic end user variable price of electricity, $LNP(WHOLESALE)$ is the logarithmic spot price at Nord Pool, $LN(K)$ is thelogarithm of the quota and $LN(CP)$ is the logarithm of the certificate price. It is important to emphasize that this regression might suffer from omitted variable bias since the administrative costs for the distributors in this case is assumed to be zero. The reasons for not including the administrative costs as a variable are simply because no reliable data could be found on monthly basis administrative costs. Because of this, the coefficients reported might be subject to an upward bias, although it is likely that this effect is marginal at worst in my regression since the administrative costs are relatively small compared to the costs included; see for example Swedish energy agency, 2010.

3.3 Data set description

The data used is gathered from statistics Sweden (Statistics Sweden, 2011), Swedish energy agency (www.energimyndigheten.se, 2011), and Nord Pool (www.nordpool.com, 2011). All prices have been adjusted to inflation by using data from statistics Sweden, with index 1996. It contains monthly data from May 2003 up to December 2010 which totals 92 observations. Because of the nature of the sources, high reliability is assumed. Correlation matrixes and descriptive statistics for the data set are shown below in table 3, table 4 and table 5.

Table 3. Correlation matrix for variables used in renewable electricity regression.

	Total consumption	Quota	Certificate price	Season	Renewable prod.
Total consumption	1.00000	-.02715	-.07572	.67597	.68971
Quota	-.02715	1.00000	.62391	0.5372	.56392
Certificate price	-.07572	.62391	1.00000	.03302	.49172
Season	.67597	.05372	.03302	1.00000	.64390
Renewable prod.	.68971	.56392	.49172	.64390	1.0000

Table 4. Correlation matrix for variables used in end user price regression.

	End user price	Quota	Certificate price	Wholesale price
End user price	1.00000	0.75385	0.62759	0.96937
Quota	0.75385	1.00000	0.62391	0.63671
Certificate price	0.62759	0.62391	1.00000	0.54111
Wholesale price	0.96937	0.63671	0.54111	1.00000

Table 5. Descriptive statistics for used variables.

Variable	Mean	Standard deviation	Minimum	Maximum	Cases
Quota	0.13347826	0. 37425817	0.740000000	0.17900000	92
Total consumption	13195554.3	2030730.11	9671000.00	17065000.0	92
Wholesale price	430.999462	171.028616	228.869097	1103.45692	92
Certificate price	269.046692	52.7714819	209.890168	357.197942	92
Season	0.65217391	0.47889026	.000000000	1.00000000	92
End user price	526.051720	194.220795	295.618945	1245.76650	92

Chapter 4

EMPIRICAL RESULTS

4.1 Quota effect on production

It is evident from Figure 4 that the quota level and the renewable production are positively correlated.

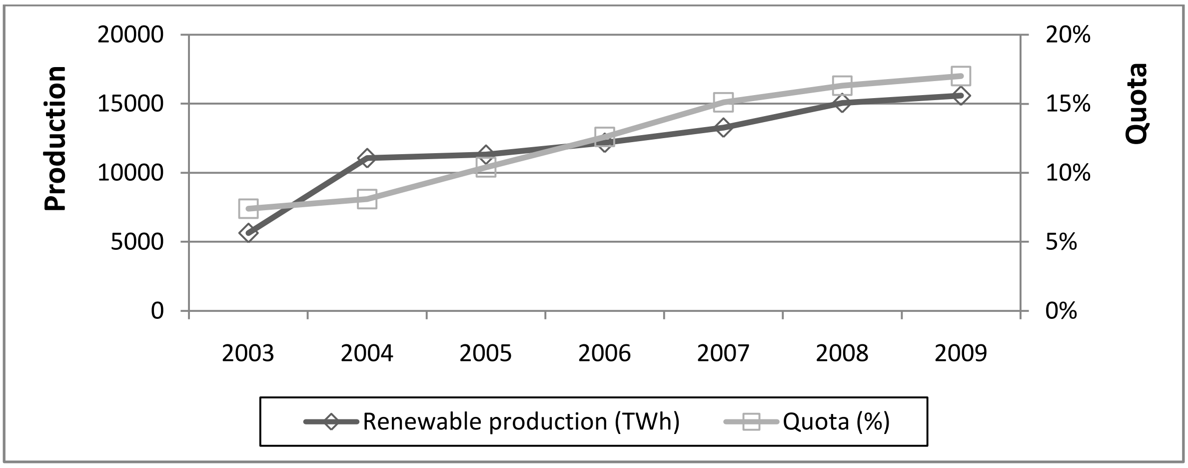

Figure 4. Production of renewable electricity and quota obligation size 2003-2009.

Source: Swedish energy agency, 2010.

Hence, inspection of this graph makes it clear that the production of renewable electricity is increasing as the size of the quota increases. However, it is still impossible to say if the quota level is a variable that affects the renewable electricity production. Therefore a regression is executed using Limdep and the results are presented in Table 6[11].

[11] Since the model suffered from autocorrelation (Ar1) Rho had to be included as a remedy to this problem; see for example Dougherty, 2007.

Table 6. Regression on the renewable electricity production.

Variable	Coefficient	T-value	Significance
Intercept	-9,29	-4,70	***
Certificate price	0,43	2,96	***
Quota	0,44	4,88	***
Total consumption	1,31	12,40	***
Season	0,13	4,54	***
Rho	0,58	6,96	***

Significance reported as *, ** and *** at the ten, five and one percent significance level respectively.

For the above regression, the adjusted r-square (R^2) is 0.90 and the f-value is 192. The coefficient of most interest, as discussed above, is the coefficient of the quota. It is significant at the 1 % level meaning that the null hypothesis, stating that $\beta_2 = 0$, can be rejected with great confidence. Hence, a 1 % increase in on the size of the quota will result in a 0.44 % increase in the renewable electricity production. The certificate price is also statistically significant and therefore the null hypothesis, $\beta_3 = 0$, can be rejected. Hence, the assumption that the certificate price does affect the production of renewable electricity seems to be valid. Also of interest is that the dummy variable, SEASON, came out positive and statistically significant which indicates that the renewable electricity producers as a group are able to increase their production on short run basis. It is also of interest that the total consumption coefficient was greater than one. This means that as the consumption increases by 1 % the production of renewable electricity will increase with 1.31 %. Hence, the relative increase of renewable electricity production is greater than the "black" electricity production for a given increase in demand. Based on the graphical examination together with the regression results it is fair to assume that $\partial z/\partial \alpha > 0$.

And hence the conclusion can be made that the production of renewable electricity will increase as the size of the quota increases. This is well in line with *ex ante* expectations. Even if the weather has a large impact on the production on renewable electricity the data makes it evident that weather by itself cannot possible has increased the production on renewable electricity for seven years in a row.

4.2 Quota effect on end user price

It is evident from figure 5 that the end user price of electricity and the quota level is positively correlated.

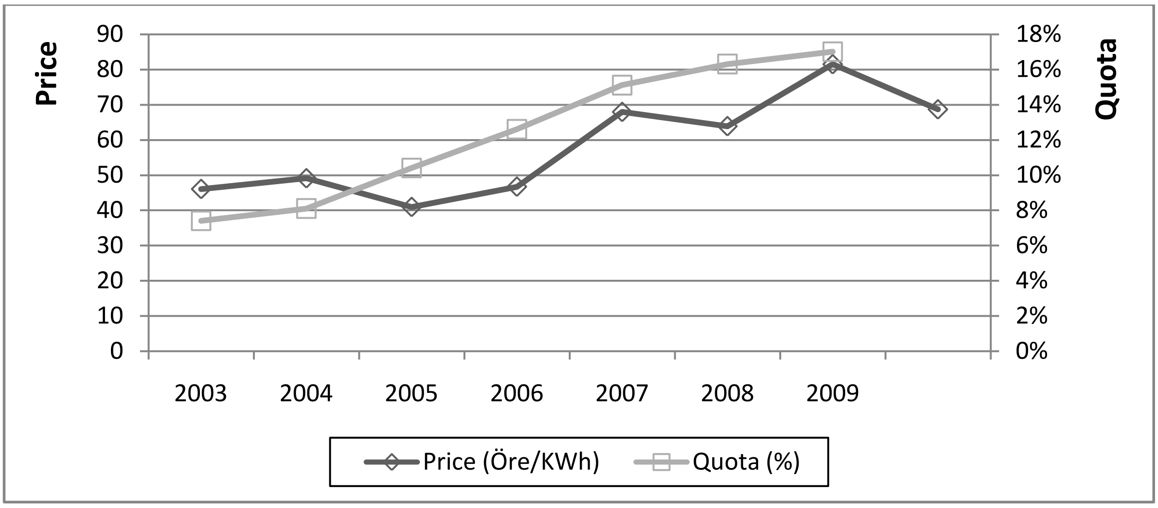

Figure 5. End user price of electricity and quota obligation size 2003-2010.[12]

Sources: Swedish energy agency, 2010 & Statistics Sweden, 2010.

To start with, figure 5 shows that the end user price has been steadily increasing since the implementation of the tradable certificate scheme along with the quota obligation. The regression results in Limdep provided the following results.

Table 7. Regression on the end user price of electricity

Variable	Coefficient	T-value	Significance
Intercept	1,37	4.96	***
Wholesale price (Nord Pool)	0,77	34.93	***
Quota	0,22	7.97	***
Certificate price	0,12	2.96	***

Significance reported as *, ** and *** at the ten, five and one percent significance level respectively.

[12] 1 öre = $\frac{1}{100}$ SEK

For the above regression the r-square (R^2) is 0.97 and the f-value is 1086. The null hypothesis, $\beta_x = 0$, can be rejected with great confidence for all coefficients. Therefore the following conclusions can be made.

- If the Nord Pool spot price goes up by 1 % the variable electricity price for the end user will go up with 0.77 %.
- If the quota goes up by 1 % the variable electricity price for the end user will go up by 0.22 %
- If the certificate price goes up by 1 % the variable electricity price for the end user will go up by 0.12 %.

Because of these results, together with the graphical inspection it is fair to assume that as the quota increases the change in the price will be positive.

i.e.,

$$\Delta p = (1-a)\frac{\partial c(y^*)}{\partial y} + a\frac{\partial h(z^*)}{\partial z} > 0. \tag{21}$$

This then also implies that the extra costs that increased "green" production results in will be bigger than the decrease[13] in marginal cost for "black" production.

To summarize the empirical results and answer the questions raised by this thesis it was found that (1) an increased quota obligation will increase the production of renewable electricity and (2) that the quota obligation size and the certificate price has significantly positive effect on the end user price for electricity.

4.3 Policy implications

The empirical results make it evident that the quota obligation along with the tradable green certificate scheme will increase the production of renewable electricity. This was also one of the main goals when the Swedish government implemented the system. It is

[13] The results do not make it possible to rule out that "black" production has a constant marginal cost, but this is, with support from economic theory, not likely.

thus fair to say that the policy was successful in terms of increased renewable production. However, the cost of electricity has increased far more then what the government expected and a large part of the increased renewable electricity production is hence paid for by the end users (e.g., Bergek and Jacobsson, (2010)). It is thus fair to conclude that the policy failed in protecting the consumer price of electricity, which *ex ante* was seen as important. It is also likely that political uncertainty regarding the tradable green certificates and the quota obligation, thanks to increased risk premiums of investments, will hold back expansion of renewable electricity production, which of course not is desirable. The bureaucratic permit process is another obstacle that needs to be handled to increase the interest in renewable electricity production. The authorities cannot promote expansion of renewable electricity production and at the same time prevent building of new facilities for the policy to work at maximum efficiency.

Chapter 5

CONCLUSSION

A more environmental friendly production of electricity is of great importance for Sweden to reduce the greenhouse gas emission and hence decrease the global warming problem. It is also necessary for the pronounced target of phasing out the nuclear power. It is because of this important that policy makers create incentives that work towards an increased renewable electricity production at the lowest cost possible. Since electricity consumption is a significant cost for most Swedish households the cost efficiency is indeed very important. Electricity consumption is assumed to be very inelastic and hence a significantly increased electricity cost will result in a substantially reduced disposable income which will create less consumption affecting other sectors. It is also of great importance that the electricity costs are held as low as possible for the Swedish industry to keep their competitive strength.

It is clear from the empirical results that the implementation of the tradable certificate scheme along with the quota obligation for sure has increased investors interest to invest in renewable electricity production. Hence, the production of renewable electricity has steadily been increasing since the implementation. This increase must be seen as positive since one of the main goals with this system was to increase this kind of electricity production. However, the cost for this increase, as can be seen on the end user price of electricity has been far higher than expected for the consumer and the system itself is far from perfect. Another big issue with the system is that it will subsidy production to renewable electricity generators that can survive in the market without any subsidies and hence will to some extent work as a rent generating machine (e.g., Bergek and Jacobsson, (2010)).

It is also important to make sure that technical development occur in the renewable energy sector, a point at which this system seems to have failed. This conclusion is based on the empirical fact that the end user price of electricity has been steadily increasing since the implementation of the tradable green certificate scheme. As the prices of the certificates tend to increase as the quota obligation increases technological development has not been great enough. This is also important in the long run since technical progress is the only way that renewable electricity production could replace greenhouse gas emitting and nuclear power without the need of market interference or a substantially higher end user price. It is therefore of great importance that policy makers evaluate what benefits this system has resulted in and then compare this to the costs of the system. If there are alternative policies that would give rise to higher incentives for technical progress along with increased production, the current system should of course be revised. Further it is also important to increase the incentives to generate more research and development as a way to get a technical progress in the renewable energy sector.

Regarding the end user price it is evident from the results that an increased quota level will substantially increase the end user price of electricity, and this is not in line with what was expected from the policymakers (Bergek and Jacobsson, 2010). To summarize the intentions of implementing the tradable green certificate scheme together with the quota obligation was very good, but further research, and alternative methods, is needed in order to evaluate the performance of this system. I do however believe that the system must, as soon as possible, be revised to increase the incentives for technical progress so that the end user price of electricity can be held down at the same time as the production of renewable electricity is increasing. The results of further development should, if successful, lower the price of the certificates because of a more cost efficient production of renewable electricity and hence a decreased end user price of electricity.

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