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The Effects of the Swedish TGC System on the Development of Wind Power Production

An empirical analysis of the impact of the certificate price

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Abstract

This thesis aims to examine how the implementation of the Tradable Green Certificate (TGC) system in Sweden has affected the development of wind power production. The main purpose is to investigate whether there exists an impact of the certificate price on the amount of wind power produced. Literature suggests that the potential for wind power production in Sweden is substantial, but also that investors are restricted due to uncertain and varying certificate prices in the TGC system. Despite the great potentials and increased production, the share of wind power production in Sweden is still comparatively small. Furthermore, the interest for investing in wind power production has started to decrease lately. The results from the empirical analysis indicate that there is no evidence of an impact of the certificate price on wind power production, neither in its present nor lagged form. Thus, the price of certificates does not seem to affect the amount of wind power produced. This is consistent with the results of previous research, indicating that the empirical analysis is credible. Potential explanations for the insignificant certificate price are lengthy instalment processes for wind power plants and uncertain certificate prices. The TGC system could therefore be argued to be somewhat inefficient in its current form. Consequently, in order for Sweden to reach the high potential of wind power production, future research could examine whether a more stable system would be suitable.

Keywords: Tradable Green Certificates, TGC, Wind Power, Renewable energy, Certificate price, Elcertifikat, Vindkraft, Förnyelsebar energi

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1. Introduction

To increase the amount of renewable electricity production in Sweden, the Tradable Green Certificate (TGC) system was implemented in 2003. Since the implementation, electricity generated from renewable resources has increased, with wind power being the renewable energy resource that has increased the most (Swedish Energy Agency, 2014c). According to Blomqvist et al. (2008), the developing potentials for wind power production are substantial. However, despite the increased generation and highly favourable wind conditions in Sweden, the share of wind power of the total energy production is still comparatively small. The share of wind power is about seven percent in Sweden (Swedish Energy Agency, 2014d), which can be compared to Denmark which has about 32.5 percent (Energistyrelsen, 2014) of the total energy production. The Swedish Energy Agency stated in their most recent report regarding the Swedish TGC system that due to uncertainties in the TGC system, such as uncertain certificate prices, the interest for investing in renewable energy resources has started to decrease (Swedish Energy Agency, 2014b).

The subject of uncertain and varying certificate prices and its effect on investments in renewable energy production has been discussed in several previous studies (Dinica, 2006; Ford et al., 2007; Klessmann et al., 2008), which will be further mentioned and discussed below. For instance, Dinica (2006) found that under a TGC system with uncertain certificate prices, investors often perceive investments as risky and hence, investors might refrain from investing if the profitability is uncertain. Furthermore, there have been several studies in which a comparison between the TGC system and the so called Feed-in-tariffs (FIT) system has been made. The FIT system is, like the TGC system, designed to increase renewable energy production and is a common support system in Europe. The main criticism of the TGC system compared to the FIT system is that the capital and its cost become a greater constraint in the TGC system. This is due to a higher risk level for investors in TGC systems, where prices of green certificates are uncertain which may lead to investors requiring higher estimated returns (Agnolucci, 2007; Mitchell et al., 2006). In the FIT system, investors are guaranteed a price that is set beforehand, which increases the possibilities for producers to stay in business. As a result, the number of producers that generate energy from renewable resources may be higher in a FIT system than in a TGC system (Jarite & Kazukauskas, 2013).

In January 2012 Sweden and Norway initiated a joint market for certificates (Swedish Energy Agency, 2014c), meaning that the trading of certificates can be made across the two countries.

Even though the certificate market for green electricity includes Norway, the analysis in this paper will be restricted to the case of Sweden. Most of the relevant data are derived before the joint market was implemented, which makes the restriction reasonable. Additionally, due to time limitations we will not do a comparison with other policy instruments that, similarly to the TGC system, aim to increase the production of renewable electricity. Thus, the previously mentioned Feed-in tariff scheme that is applied in several countries will not be examined in this paper.

1.1 Purpose

The objective of this thesis is to examine how the implementation of the TGC system in Sweden has affected the development of wind power. We chose to focus on wind power production because it is the renewable energy resource that has increased the most since the implementation of the TGC system (Swedish Energy Agency, 2014c). Furthermore, it is considered to be the renewable energy resource with highest potential in Sweden in the future. Due to the previously mentioned problematic circumstances about the TGC system, we chose to focus on how uncertain and varying certificate prices affect production and investment in wind power. The purpose will therefore be to examine whether there exists an impact of the certificate price on the amount of wind power produced. Moreover, we will analyse both current and delayed effects.

1.2 Method

To examine the relationship between certificate prices and wind power production, we used an econometric analysis, in the form of a time series regression. Econometric analyses can give empirical content to economic theory and are therefore a useful way to empirically analyse observed data and to obtain numerical results (Gujarati & Porter, 2009). The first step in the econometric analysis was to state the hypotheses and to specify the econometric model. We chose a time series regression as a model to be able see how the amount of produced wind power changes over time and furthermore, to be able to control for other factors that could affect wind power production. Secondly, we made a thorough enquiry in order to identify what data would be needed for the analysis. Both previous studies on the subject and information about different factors affecting wind power were studied for this purpose. Thereafter, we obtained the required data between the years 2003 through 2014 with monthly observations, with the intention to get a large sample. A large sample is useful since it increases the possibilities to make statistical inference and getting more reliable results

(Gujarati & Porter, 2009). We used the method of Ordinary Least Squares (OLS) as the econometric approach to reach the estimations. In order to justify the OLS estimators, we tested the underlying asymptotic assumptions to confirm that they were satisfied for our models. A critical approach of potential omitted variables was also made. Next, the parameters of the econometric model were estimated and analysed. The software used for the estimation was Stata, which is a statistical software that can be used to do data analyses. After obtaining our results, we discussed and connected them to previous research. Finally, we summarised our findings and suggested directions of further research.

2. Policy framework and previous research

The policy framework of the TGC system will be explained in this section. Furthermore, previous work on the subject of the TGC system and wind power production will be discussed.

2.1 The TGC system in Sweden

The TGC system was implemented in Sweden in 2003 with the objective to increase the amount of renewable electricity production with a total of 25 terawatt-hours (TWh) by year 2020 compared to year 2002 (Swedish Energy Agency, 2014b). Electricity certificates acts as a financial support for producers of renewable electricity. Moreover, the increase in electricity production from renewable resources is supposed to occur in a cost-effective way since the system is market based (Swedish Energy Agency, 2014c).

In the Swedish TGC system, power producers receive one electricity certificate for each megawatt-hour (MWh) of renewable electricity that they produce, over a maximum of 15 years. The certificates are sold in a market for certificates and the price is determined by the relationship between supply and demand. Producers thus receive additional revenue, in addition to the power price, by selling their certificates. This is intended to increase the incentives for producing electricity from renewable resources rather than from conventional production (Swedish Energy Agency, 2014c). Demand for certificates is created from the fact that power suppliers and certain power customers are obligated to purchase electricity certificates. The amount of certificates they are obligated to purchase corresponds to a certain share of their electricity sales or consumption. The share is known as quotas, which are predetermined up until year 2035 by the government, and are designed to stimulate the development of renewable power production in accordance with the target for renewable energy. The quota levels are aimed to keep the certificate price stable and are calculated through predictions of the amount of future renewable electricity production. Furthermore, the quota levels gradually increase until the year 2020, which is supposed to result in an increased demand for certificates. The trading primarily occurs through bilateral agreements between electricity producers and quota obligated market members, as well as through brokers (Swedish Energy Agency, 2013b).

The cost of the electricity certificates is included in the electricity bill and thus, it is the end users of electricity that pays for the development of renewable electricity production. The market members with quota obligation must each year cancel certificates to fulfil the quota obligation. The certificates that have been issued but not cancelled are called the electricity certificate surplus. In years when the issued electricity certificates are higher than demand, the surplus increases, resulting in decreasing certificate prices (Swedish Energy Agency, 2014c).

The energy resources that are accounted as renewable resources, and hence entitle producers to certificates are: biofuel, geothermal energy, solar energy, hydropower, wind power and wave power. In Sweden, wind power is the energy resource that dominates the development of renewable electricity production and accounted for about 63 percent of the new production in Sweden in the year 2013 (Swedish Energy Agency, 2014c). However, the time from a decision of investing to the installation of the wind power plant can often be lengthy. The total process can vary from 2 up to 15 years (Energinytt, 2012; Hållén, J., 2015; Vattenfall, 2015). This is due to, for example, processing time for building permits and appeals from people living close to where the wind power plant is planned to be built.

2.2 Previous research

In this section, previous research about the TGC system is examined. Furthermore, previous empirical researches on the TGC system are described. They were used as a basis when we chose the explanatory variables and made the model specification.

2.2.1 Previous research about the TGC system

Blomqvist et al. (2008) investigate how the physical, technical and economic conditions affect the profitability for wind power projects. They have also made a survey of Swedish electricity production companies, in which they aim to investigate how different factors affect investment decisions for wind power plants. The result of the survey indicates that the factor that has the most significant impact on investment decisions is “uncertainty regarding the electricity certificate system (e.g. in the long-term perspective and price levels)” (translated from Swedish). Since the certificate price is set by the relationship of supply and demand, the result is that the price is uncertain (Swedish Energy Agency, 2014c). The Swedish Energy Agency (2014b) has also observed this problem, where investors and banks have pointed out that the TGC system has a weakness with unpredictable prices. Due to varying certificate prices, revenues from renewable energy production projects are uncertain which may cause investors to perceive projects as too risky to invest in. This has resulted in a decreased interest by investors and banks to invest in renewable electricity production (Swedish Energy Agency, 2014b).

Investment in renewable electricity production is also investigated by Dinica (2006), in which different support systems for the diffusion of renewable energy technologies are examined from an investor perspective. Dinica (2006) concludes that even though an entirely risk free policy may not be feasible, it is important that a policy instrument allows investors to be able to predict the revenues on a long-term basis. This is especially important when it comes to renewable energy generation since price volatility can be even more exacerbated by variations of natural resources from year to year (Dinica, 2006). Finally, it is concluded that profitability gives fundamental incentives for stimulating investors to invest in renewable energy production. Ford et al. (2007) have similar arguments as Dinica (2006), arguing that certificate prices are highly uncertain and volatile. They discuss that new investments in renewable energy production, in reaction to high certificate prices, may not arrive in time to prevent a period of certificate shortages. They argue that volatile certificate prices would cause investment cycles that would lead to even more volatile prices.

Klessmann et al. (2008) examine how renewable electricity producers are integrated into the electricity market through different support systems in Germany, Spain and the UK. They conclude that the risk exposure is the highest in the UK, which uses a TGC system to increase renewable electricity production. To compensate for the higher risk, investors will require higher expected returns on their investments which lead to under-investment and higher certificate prices (Klessmann et al. 2008).

2.2.2 Empirical research

In an article by Fagiani and Hakvoort (2014) the role of regulatory changes on the volatility of certificate prices is investigated in the Swedish-Norwegian TGC market. They are using an econometric approach to investigate how regulatory changes affect the volatility of the certificate price. Volatility in certificate price represents a large risk for renewable energy producers, for which investors will require higher returns. Furthermore, regulatory uncertainty may also increase volatility in the certificate price, which means that investors are exposed to a regulatory risk as well (Fagiani & Hakvoort, 2014). In their econometric approach, to examine the volatility in the certificate price, the main explanatory variables that they use are electricity price and an equity index. The equity index is a variable that represents the economic activity at different points in time, which they find has an important role in determining the demand of energy commodities and electricity. They argue that there is no increased price stability since the joint certificate market between Sweden and Norway was created. Finally, they conclude that regulatory changes increase the volatility of certificate prices in the Swedish certificate market and furthermore, that price volatility intensifies price risk and may restrain investors.

In an article by Carley (2009), an investigation of an American policy instrument called Renewable Portfolio Standard (RPS) policy is made. RPS policies are designed to increase the percentage of the total amount of renewable energy. It is similar to the Swedish TGC system since it is based on so called Renewable Energy Certificates (REC), which can be traded between states. Carley (2009) used a fixed effects model with renewable energy production as a dependent variable and with several explanatory variables. It is found in the model that the RPS implementation is not a significant variable for the percentage of renewable energy generation out of the total energy generation. However, Carley (2009) concludes that for each additional year that a state has an RPS policy in place, the total amount of renewable energy generation is found to increase. Furthermore, it is found that states with RPS policies do not have higher rates of renewable energy than states without the policy, holding all else constant, which Carley (2009) concludes to potentially be a shortcoming of RPS policies. Furthermore, the explanatory variables that are found to be significant for renewable energy production are political institutions, natural resource endowments, gross state product per capita, electricity use per person, and electricity price.

Other factors found by Blomqvist et al. (2008) to have an important impact on the wind power development are interest rate, investment costs and the price of biofuel. To begin with, they found that when interest rate decreases, wind power production is expected to increase, due to lower cost for capital. Similarly, they concluded that lower investment costs also are expected to increase the wind power production. The price of biofuel was also found to have a significant impact on wind power production. For instance, a high price of biofuel will make biofuel less competitive in the TGC system and thus, give the wind power production more space to develop (Blomqvist et al., 2008).

3. Data and model specification

This section contains a thorough description of the collected data and the variables that are used in the regression, which are founding the empirical analysis. Thereafter follows a critical approach of the model along with its limitations. Finally, the model specification and the hypotheses are presented.

3.1 Data variables

In this section, the chosen variables for the empirical analysis are defined and motivated. Descriptive statistics along with the Augmented Dickey-Fuller (ADF) tests for stationarity are found in Appendix A.1 and A.4, respectively.

3.1.1 Dependent variable

To examine how the wind power production has changed, we chose the dependent variable to be Total Wind Power Production measured monthly in GigaWatt-hour (GWh). By choosing this as the dependent variable, it is possible to examine how the certificate price affects the production of wind power, while controlling for other factors. The development of wind power production presented in Figure 1, indicates a clear exponential trend. By transforming the variable into logarithmic form, the data fits a better line and the variance is smoothed, as presented in Figure 2. For that reason, the logarithmic form of the wind power production variable is the one we will use in the regression. Furthermore, the analysis of the estimated parameters is enabled to be made in a percentage change. The data of the total wind power production, presented in Figure 1 and 2, ranges between the years 1997 through 2014 and are collected from the Statistics Sweden (SCB, 2015). Before the year 1997, the wind power production was a marginal energy resource and hence, the reason for why the data starts at

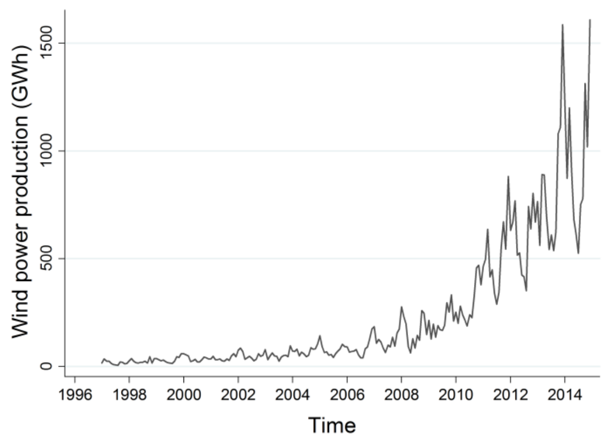

Figure 1: The development of wind power production in GWh

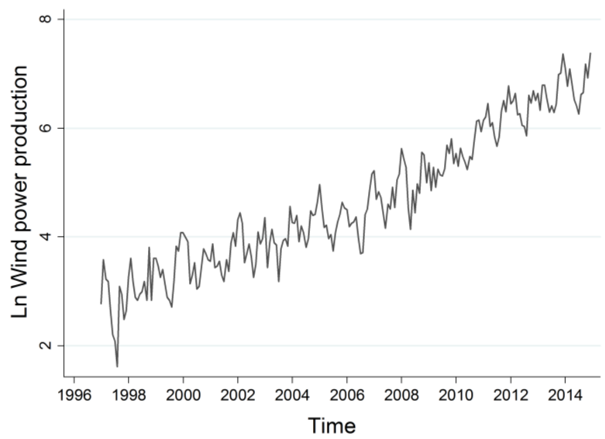

Figure 2: The logarithmic form of wind power production over time

that time. Thereafter, when we examine how the certificate price affects wind power production, we will only use data between the years 2003 through 2014. The reason for a shorter time period in our econometric analysis is that the TGC system was implemented in 2003 and thus, the data are only available from that time. Moreover, the ADF test indicates stationarity in the detrended version of the logarithmic wind power production variable (see Appendix A.4).

An optional choice of dependent variable could be installed wind power capacity, since it might be better of capturing the actual increase of installed wind power plants. It would further not vary as much as wind power production due to the variation and seasonality in wind. However, we did not find any monthly data for such a variable. Moreover, the variable for wind power production is a better estimate of how much energy production wind power plants actually can generate.

3.1.2 Explanatory variables

The explanatory variables are the variables that are likely to explain the variance in the dependent variable (Wooldridge, 2014). The variables that we chose in this regression are both factors that are connected to the TGC system, and also macroeconomic factors that have been found to be significant in earlier studies. The definitions of the variables are presented in Table 1, where their predicted impact on the dependent variable also is presented.

Variable	**Description**	**Predicted Impact**
Certificate price	Monthly change in average certificate price (ΔSEK/unit)	$+$
Quotas	Monthly change in percentage points of quotas (Δ%)	$+$
Green party votes	Monthly change in percentage points of votes (Δ%)	$+$
Electricity use	Monthly average of electricity use (GWh)	$+ \text{ or } -$
Wind power plants	Monthly average of total number of wind power plants	$+$
Oil price	Monthly worldwide oil price ($/barrel)	$-$
Official bank rate	Monthly change in percentage points of interest rate (Δ%)	$-$
Economic activity	Monthly stock market development (%)	$+$
Electricity price	Monthly change in average electricity price (ΔSEK/MWh)	$+ \text{ or } -$

Table 1: The explanatory variables and their predicted impact on wind power production. Expressed in the unit form they have in the regression. Δ refers to first difference.

The primary explanatory variable of interest is the electricity certificate price. The data are collected from Cesar (2015), which is the Swedish Energy Agency's system for buying and selling certificates. The data represent the average monthly certificate price in Swedish Krona (SEK) adjusted for inflation (base year = 2010), and the evolution of the price is presented in

Figure 3. Descriptive statistics for the certificate price, found in Appendix A.1, contain 139 observations and ranges between a minimum value of 110.9 SEK per certificate and a maximum value of 330.4 SEK per certificate in the data set. The mean value of 221.4 SEK per certificate represents the central tendency of the distribution. Furthermore, the standard deviation of 47.08 SEK is measuring the spread around the mean in the sample. An indication from the standard deviation is that the dispersion around the mean is quite high, and for wind power operators it can be useful as a measure for how varying and uncertain the extra income from the certificates is.

The predicted impact of the certificate price on the amount of wind power produced should be positive, as a higher certificate price would yield higher revenues for wind power producers. However, since the certificate price is varying and investments in wind power take time to implement, the price effect could be delayed or not exist at all (Blomqvist et al., 2008). By studying Figure 1, the wind power production does not seem to start increasing significantly until about year 2010, which is about seven years after the TGC system was implemented. Assuming that the TGC system has a positive impact on wind power production, this could be an indication of the lengthy process of investing in wind power plants. Therefore, we will further analyse through a test whether or not lagged variables for the certificate price are significant for the model. Since the time series for certificate price indicates to be integrated of order one and thus follows a unit root process, we will use the first difference of the variable in the model. First difference is a transformation on the time series constructed by taking the difference of adjacent time periods, where we subtract the earlier time period from the later time period. The first difference of the certificate price is stationary according to the ADF test (see Appendix A.4) and is presented in Figure 4.

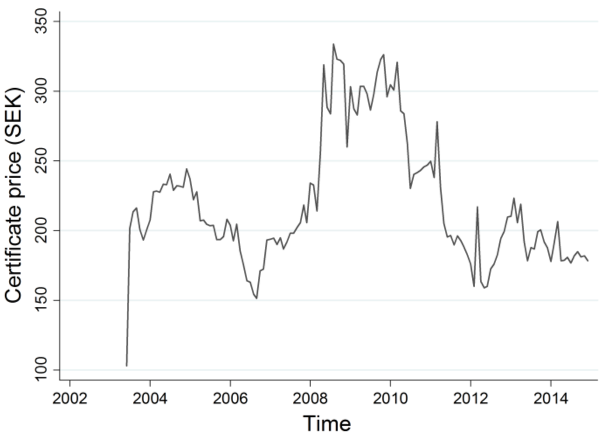

Figure 3: The development of the certificate price over time

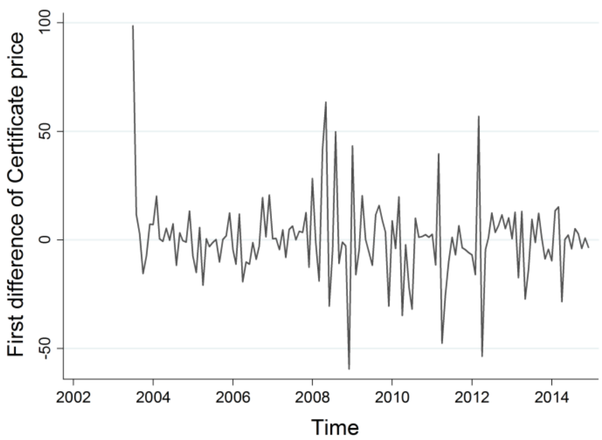

Figure 4: The first difference of the certificate price over time

An additional factor connected to the TGC system is the quotas, which is thus an important variable in this econometric analysis. The quota levels are, as previous mentioned, yearly fixed at a certain level set by the government. Even though the quotas are fixed in advance the expected impact is positive, since higher levels of quotas are found by Blomqvist et al. (2008) to have a positive impact on the development of wind power production. However, in the similar econometric study made by Carley (2009), the RPS policy was found insignificant in explaining renewable energy production. We will thus further investigate what impact the quota variable will have in our regression. By taking the first difference of the variable, it allows the time series to be stationary, which is confirmed through the ADF test (see Appendix A.4). The quota variable will thus be defined as the first difference in the regression.

To analyse the explanatory variables of interest, we chose to add selected control variables which are intended to decrease the risk of biased estimators. Moreover, the control variables are aimed to help explain the variation in the dependent variable and make the model more reliable. A variable found to be significant in a similar regression analysis is the electricity use (Carley, 2009) and hence, we chose to add it to our regression. The data for this variable are collected from Statistics Sweden (SCB, 2015) and are measured monthly in GWh. The predicted impact of increased electricity use is positive, since wind power producers are likely to supply more in order to meet a higher demand. However, Carley (2009) found that it has a negative impact and thus, we will investigate this further in the regression. Moreover, the ADF test indicates stationarity in the detrended and seasonally adjusted data for electricity use (see Appendix A.4).

An additional factor that we chose to add to the model is electricity price, which also has been found by Carley (2009) to have a significant impact on renewable energy production. The data for electricity spot price are collected from NordPool Spot (2015), which is the power market in the Nordic countries, and are measured monthly in SEK per MWh (base year = 2010). The predicted impact of an increase in electricity price on wind power production should be positive, since it would yield higher returns for investors. However, Carley (2009) found that electricity price has a negative impact, which we will further investigate in the regression. In addition, we will investigate potential lagged effects of the variable due to the lengthy implementation process for wind power investments. Moreover, by transforming the variable into first difference, the ADF test indicates stationarity in the time series (see Appendix A.4).

The wind power production could further be explained by a variable that measures the economic growth and activity, which has been found to have an important role in determining the demand of energy commodities and electricity (Fagiani & Hakvoort, 2014). To measure economic activity, we chose to use a variable for the stock market index development as monthly percentage change, collected from Nasdaq (2015) and the OMX Stockholm All-Share Index is the index that we used. A variable representing the stock market index is found in previous research to be significant when analysing the certificate price (Bredin & Muckley, 2011; Creti et al., 2012; Fagiani & Hakvoort, 2014) and it will reflect the financial and economic conditions. The predicted impact of increased economic activity should be positive since increased growth and activity likely would result in higher demand for electricity and higher investments. The data for stock market development show stationarity through the ADF test (see Appendix A.4).

To control for the impact of environmental awareness in the society, we chose a variable representing votes for the Green Party in Sweden. The data are collected from Statistics Sweden (SCB, 2015) and reflect the share of votes for the Green Party if there would be an election. Theoretically, the impact of a higher share of votes for the green party could indicate a higher environmental awareness in the society and thus, higher demand for renewable energy productions. However, we suspect that the increase in wind power production to a greater extent depends on profitability of the investment rather than environmental awareness. The variable measuring environmental awareness may for that reason not have a large effect. In the result section, we will be able to analyse more confidently how this variable indicates to influence the wind power production. Additionally, we will investigate whether there are any delayed effects from the environmental awareness variable on wind power production considering the lengthy implementation process for wind power investments, as earlier mentioned. Moreover, the first difference of the variable for green party votes is stationary according to the ADF test (see Appendix A.4).

To control for available production potentials, we chose total number of wind power plants as an additional explanatory variable. The predicted impact of an increased number of wind power plants would be positive, since an additional wind power plant increase the potential for wind power production. The data are collected from the Swedish Energy Agency (2015), and the ADF test shows that the detrended variable is stationary (see Appendix A.4). However, this variable could be misleading if the technology and effectiveness in wind power plants have increased, signifying that one power plant may replace several less effective power plants.

A macroeconomic factor that is found to affect the development of wind power plants is the imputed rate of interest (Blomqvist et al., 2008). We chose to use the official bank rate to measure for this, and the data are collected from the Central bank of Sweden (Sveriges Riksbank, 2015). The predicted impact of an increased interest rate on wind power development is negative, since an increased interest rate makes investment costs more expensive (Burda & Wyplosz, 2013). Additionally, we suspect that there might be delayed effects of the interest rate on wind power production and thus, we will analyse lagged variables as well. Moreover, by transforming the time series into first difference, the ADF test indicates stationarity in the data (see Appendix A.4).

An additional variable that we chose to use was crude oil price, collected from United Nations Conference on Trade and Development (UNCTAD, 2015), and is measured in dollars per barrel. According to the Swedish Energy Agency (2012) the electricity market is competitive and hence, we chose to control for oil price in case it has an effect on the amount on wind power produced. The variable could also be motivated because of, for instance, a positive correlation between the electricity price and oil price, as well as a negative correlation between economic activity and oil price (see Appendix A.5). Excluding oil price could cause the estimators of electricity price and economic activity to be omitted variable biased (Wooldridge, 2014). The predicted impact of an increased oil price would be an increased economic incentive to invest in renewable energy. However, as the price of manufacturing wind power plants may also be affected by the oil price, the total effect is somewhat uncertain. In addition, we will investigate potential lagged effects of oil price on wind power production due to the lengthy implementation process for wind power plants. Moreover, the detrended variable for oil price is stationary according to the ADF test (see Appendix A.4).

Several of the time series are indicated to have a trend over time. To be able to control for these time trends, we will include a time trend variable in the model. In addition, since our data set consists of monthly observations, we defined a set of dummy variables indicating the different months. As can be seen in Appendix A.6, the monthly dummies and the time trend variable are significant for the model and hence, we will include these in order to detrend the regression as well as adjust for seasonality (Wooldridge, 2014).

3.2 Limitations

A flawless model with entirely consistent estimators is hard to reach. To accomplish such a model, the so called asymptotic assumptions need to be satisfied. Statistical tests for the underlying asymptotic assumptions, how well they are met for this model are found in Appendix A.2 - A.5. This section will cover an investigation of how certain omitted variables might affect the results in the model.

Explanatory variables included in the regression might be biased or inconsistent if they are correlated with factors in the error term. Due to lack of data, the variables are probably correlated with omitted factors. However, it might be possible to deduce in which direction the estimators are biased and thus learn if they are likely larger or smaller. The certificate price is according to the Swedish Energy Agency (2013a) correlated with the electricity price, the size of the surplus of certificates, and regulation changes. However, the electricity price and regulation changes are not causing any problem since they will be controlled for in the model. Consequently, the certificate price estimator is biased due to the omitted variable of certificate surplus. There are potentially other factors that the certificate price is correlated with but not controlled for. However, we chose to focus on the surplus of certificates since it is a major part of the system. To get a better interpretation of the estimated coefficient of certificate price, we investigate in which direction it is biased due to the omitted variable of certificate surplus:

$$\beta_{Certificate\ surplus} < 0$$

$$Corr(Certificate\ price, Certificate\ surplus\ ) < 0$$

The correlation between the certificate price and the certificate surplus would be negative. Furthermore, an increase in the certificate surplus would probably have a negative impact on the wind power production, since it is associated with a lower certificate price. When both the estimated coefficient of the omitted variable and the correlation are negative, this indicates a positive biasedness (Wooldridge, 2014). Consequently, the certificate price would thus have a positive bias estimator, indicating that the estimator on average likely is larger than the true parameter.

There are additional factors that most likely have an impact on wind power production, however, all of them were not able to control for due to data unavailability. We will therefore investigate the predicted impact of the most essential factors. Such a factor is, to begin with, the price of biofuel, which is found by Blomqvist et al. (2008) to have a significant impact on wind power development. A high price of biofuel will make biofuel less competitive in the TGC system and thus, give the wind power production more space to develop. According to the Swedish Energy Agency (2014a), there has been an upward tendency for biofuel prices the last ten years with some disturbances in the end of the period, which likely has affected the wind power production in a positive way. Unfortunately, this cannot be confirmed by the regression due to the lack of data. The partial effect of biofuel price on wind power production would theoretically be positive. Therefore, the results of the OLS estimators in the model might be positively biased if a positive correlation with the price of biofuel is present and negatively biased if a negative correlation is present.

Another factor that is crucial for wind power production is the natural resource of wind potential (Svensk Vindenergi, 2008). Periods of more windy weather conditions are beneficial for wind production and hence, the theoretical relationship between the variables is positive. Because of the difficulty of measuring wind potential as a whole for Sweden, since wind varies between locations, we will not include this factor in the analysis. Nevertheless, we do not suspect a strong correlation between the wind potential and any of the explanatory variables included, which reduces the risk of biased results.

A factor that has a potential negative impact on the development of wind power production is the cost for wind power projects. Increased prices for wind power equipment and construction jobs have been observed by Blomqvist et al. (2008), which are a result from the growing demand while the supply is too small. An additional factor, not included in the model, with a potential negative impact on the dependent variable is the time process for getting a license in order to start a wind power plant (Blomqvist et al., 2008). Including these factors would probably help explaining some of the variance in the dependent variable. The partial effect of these variables on the wind power production would be negative. Thus, the OLS results might be positively biased if there is a negative correlation with the included variable to one of the omitted, and negatively biased in the presence of a positive correlation. For instance, prices for equipment might be positively correlated with economic activity, causing the estimator for economic activity to be negatively biased.

The amount of electricity produced by alternative renewable resources might influence the amount of wind power produced, as they are substitutes. For instance, if the certificate price increases and investors are interested in investing in renewable energy resources, they might choose to invest in other energy resources than wind. However, as previously mentioned, wind power production is the renewable energy resource with highest developing potential in Sweden (Blomqvist et al., 2008). Thus, it should be the renewable energy resource in which most potential investors are interested in. Nevertheless, alternative renewable resources might still have an impact if they were to be included in the model. Assuming they act as substitutes, the predicted sign of the coefficient for the alternative resources variable should be negative when explaining wind power production.

Furthermore, as can be seen in the correlation matrix in Appendix A.5, there is a negative relationship between quotas and the number of wind power plants, which does not correspond to the predicted relationship. A potential explanation could be that due to changes in efficiency or better technology in the wind power plants, less wind power plants need to be installed for the same level of efficiency. Data for measuring efficiency were however not available. The predicted correlation between number of wind power plants and efficiency would thus be negative while the partial effect of efficiency on wind power would be positive. This would result in a negatively biased estimator for the number of wind power plants in the regression, indicating that the estimated coefficient tends to underestimate the true impact.

The wind power production is also affected by the price for carbon emission allowances in the Emission Trading System (ETS), and the impact is negative according to Widerberg (2011). An increase in the ETS price is found to lead to a decrease in the wind power production. Thus, the combination of these two policy instruments gives unexpected and unwanted results (Widerberg, 2011). Due to unavailable data, the model fails to capture this negative partial effect from ETS prices on the dependent variable. However, the electricity price is highly correlated with the price of emission allowances, in a positive direction. This is because the marginal production, which is price setting in the electricity system, largely consists of fossil energy (Elforsk, 2008). The omitted variable of ETS price is therefore causing the electricity price estimator to be negatively biased.

3.3 Model specification

Equation (1) illustrates the econometric model, named Model 4 in Table 2. In the model, $log(Windpro_t)$ is the dependent variable transformed into logarithmic form. On the right side of the equation, all the explanatory variables are presented along with a time trend variable, the seasonal dummies and the error term, u_t. A clarification of the abbreviations is found in Appendix A.5.

$$log(Windpro_t) = \beta_0 + \beta_1 \Delta Certpr_t + \beta_2 \Delta Quota_t + \beta_3 \Delta Elpr_t$$
$$+\beta_4 Ecoact_t + \beta_5 Eluse_t + \beta_6 \Delta Rate_t + \beta_7 \Delta Votes_t + \beta_8 Oilpr_t$$
$$+\beta_9 Nowind_t + \beta_{10} t + \beta_{11} Jan_t + \beta_{12} Feb_t + \beta_{13} Mar_t + \beta_{14} Apr_t + \beta_{15} May_t$$
$$+\beta_{16} Jun_t + \beta_{17} Jul_t + \beta_{18} Aug_t + \beta_{19} Sep_t + \beta_{20} Okt_t + \beta_{21} Nov_t + u_t \quad (1)$$

Equation (2) reflects an econometric model allowing for the certificate price to have two, three, four, and five years lagged effects on the wind power production, a so called finite distributed lag model. We will carry out this model in addition to our main regression model in order to test whether or not any lagged variables are significant and thus should be included (Wooldridge, 2014). Furthermore, we will construct similar models as Equation (2) for certain control variables and test whether they have significant lagged effects as well.

$$log(Windpro_t) = \alpha_0 + \delta_0 \Delta Certpr_{t-24} + \delta_1 \Delta Certpr_{t-36} + \delta_2 \Delta Certpr_{t-48}$$
$$+\delta_3 \Delta Certpr_{t-60} + \delta_4 t + monthly\ dummies + u_t \quad (2)$$

3.4 Hypotheses

We aim to test the hypothesis that the certificate price has a significant effect on the amount of wind power produced and therefore, we derive two sets of hypotheses. The first is intended to test the static effect from the current certificate price, and the second is intended to test the effects from the lagged certificate price variables.

- **Hypothesis 1:** Associated with Equation (1). The null hypothesis (H_0) states that the certificate price has no impact on the wind power production, while the alternative hypothesis (H_A) states that the certificate price has a significant impact on the wind power production.

$$H_0: \beta_1 = 0$$
$$H_A: \beta_1 \neq 0$$

- **Hypothesis 2:** Associated with Equation (2). The null hypothesis (H_0) states that none of the lagged variables have an impact on the wind power production, while the alternative hypothesis (H_A) states that at least one of the lagged variables have an impact on the wind power production. If we can reject the null hypothesis there is evidence of a delayed effect from one or more of the lagged variables, and in such case we will include the potential variables to Equation (1).

$$H_0: \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$$
$$H_A: At\ least\ one\ of\ the\ coefficients\ are\ significantly\ different\ from\ zero$$

4. Empirical results and analyses

The results from the regressions are presented in Table 2, in which the OLS estimates for five different models can be found. The five models, with wind power production in logarithmic form as the dependent variable, include various number of control variables and are implemented to make the hypothesis testing feasible.

Variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Certificate price	-0.000557 (0.00120)	-0.000538 (0.00120)	-0.00111 (0.00110)	-0.00102 (0.00108)	-0.000916 (0.00108)
Quotas		0.0432 (0.0441)	0.0198 (0.0402)	0.0543 (0.0387)	0.0503 (0.0443)
Electricity price			-0.000715*** (0.000176)	-0.000363* (0.000197)	-0.000240 (0.000231)
Economic activity			-0.00734 (0.00446)	-0.00882* (0.00462)	-0.00986* (0.00544)
Electricity use			-0.000101** (0.0000463)	-0.000138*** (0.0000465)	-0.000129** (0.0000552)
Interest rate			0.181** (0.0891)	0.186** (0.0914)	0.238** (0.105)
Green Party votes				-0.00759 (0.0467)	-0.0113 (0.0497)
Oil price				-0.000514 (0.00154)	-0.000196 (0.00179)
Number of wind power plants				0.00670*** (0.00152)	-0.00652 (0.00626)
Interest rate 3 years lagged					-0.182* (0.0986)
Time trend	0.0239*** (0.000555)	0.0240*** (0.000563)	0.0233*** (0.000591)	0.0142*** (0.00260)	0.0398*** (0.0113)
Monthly dummies	Yes	Yes	Yes	Yes	Yes
Constant	-8.481*** (0.337)	-8.536*** (0.341)	-6.323*** (0.886)	-1.335 (1.606)	-15.05** (5.852)
Observations	138	138	135	126	90
R-squared	0.0016	0.0222	0.4381	0.4616	0.5129

Table 2: Time series regressions with wind power production in logarithmic form as dependent variable. Standard errors in parentheses. *** indicates significance at 1% level, ** at 5% and * at 10%

The regression in Model 1 is a simple regression model, since it consists of only the certificate price as an explanatory variable. The estimated coefficient for certificate price is statistically insignificant and thus, we fail to reject the null hypothesis of Hypothesis 1 at this stage. This means that there is no evidence of an impact from the certificate price on wind power production, neither statistically nor economically. The R-square for the model is low, indicating that only 0.16 percent of the variation in wind power production is explained by the certificate price. However, the low explanatory power is not too unexpected since several factors affecting wind power production are included in the error term.

The regression in Model 2 includes certificate price and quotas, which are the variables most connected to the TGC system. From the results, we found that the estimated coefficient for certificate price still is insignificant. Since the certificate price and the quotas are positively correlated (see Appendix A.5), the certificate price in Model 1 was probably taking account for some effects actually caused by the quotas. The estimator for quotas is indicated to have a positive impact on the wind power production, but is statistically insignificant for the model. This result is consistent with the results of both Blomqvist et al. (2008) and Carley (2009), whose studies we previously mentioned. According to the regression in Model 2, where only the variables connected to the TGC system are included, there is no evidence of a statistically significant impact from neither the system as a whole nor the certificate price in specific. Thus, we fail to reject the null hypothesis of Hypothesis 1 in this stage as well.

In Model 3, we have added electricity price, electricity use, economic activity, and interest rate as control variables to the regression. These are added in this stage as they have shown to be significant in similar studies for explaining the variation both in wind power production and the certificate price. Both electricity price and electricity use are found to have a negative impact on the wind power production, holding all else constant, and they are both statistically significant. This result is thus the opposite from the predicted impact that we mentioned earlier. However, it is consistent with the empirical research by Carley (2009), which we previously mentioned, in which the equivalent coefficients also indicated a negative impact along with statistical significance. It is possible that an increase in demand for electricity would increase electricity generation from base load power sources, which could be an explanation to the negative sign of the coefficient for electricity use. Moreover, as earlier mentioned, the omitted variable for ETS price is likely causing a negative biasedness of the estimator for electricity price. It may partly explain the negative sign since the electricity price estimator likely is lower than the true parameter. We can further not rule out that the result of the electricity price suffers from reverse causality, which therefore could be an additional explanation for the unexpected result. Thus, some of the variation in electricity price could rather be an effect from the variation in wind power production. Furthermore, R-square has increased considerably between Model 2 and 3, which is probably due to the high correlation between the variable for electricity use and wind power production (see Appendix A.5).

The estimated coefficient for economic activity does not correspond to the predicted impact either. However, it is statistically insignificant for the model and we can therefore not draw any precise conclusions from the variable. Furthermore, the regression indicates that an increased interest rate would have a positive impact on wind power production. This is contrary to economic theory, in which an increased real interest rate is assumed to have a negative relationship with investments (Burda & Wyplosz, 2013). The result could be misleading due to the inflation, which is not controlled for. However, as the investment process of wind power plants is lengthy, the effect of changes in the interest rate might thus be delayed. This will be further analysed in Model 5.

By adding control variables to the regression in Model 3, the explanatory variables from Model 2 decrease in its impact. This is probably because they were overestimated before, as they took credit for the omitted variables that they were correlated with. The certificate price was possibly overestimated due to the omitted variable of electricity price, since it is an important factor related to the certificate price (Swedish Energy Agency, 2013a). As can be seen in the correlation matrix in Appendix A.5, there is a negative correlation between electricity price and certificate price. The negative correlation combined with the negative impact of electricity price, was likely causing a positively biasedness of the certificate price in the previous models. It is however still insignificant and hence, we fail to reject the null hypothesis.

Three additional control variables are included in the regression in Model 4. These are green party votes, oil price, and number of wind power plants. The estimated coefficient for green party votes is neither statistically significant nor economically significant, and its sign is contrary to the predicted impact. As previously mentioned, it was intended to indicate a measure for environmental awareness. However, due to its insignificance for the model, we can assume that production in wind power is rather due to economic incentives, than environmental awareness. On the other hand, the variable might not be a good measure for environmental awareness in society, since it is not certain that an environmentally interested individual votes for the green party. It is therefore hard to draw any precise conclusions from this result.

The estimated coefficient for oil price is also insignificant for the model. Either it suffers from an omitted variable bias or it is not significant for explaining the variation in wind power production. However, the total effect of oil price on wind power production is from our predictions somewhat uncertain. This is because we suspect both a positive and a negative impact from an increased oil price. The positive is due to an increased competitiveness for wind power in the electricity market, and the negative is due to potential increased prices for manufacturing of wind power plants. These potential positive and negative effects from changes in oil price on wind power production may thus offset each other.

The variable for number of wind power plants is however found to be statistically significant at one percent level. It indicates a positive impact on wind power production, as expected from the predicted impact. One additional wind power plant would, suggested by the model, result in about 0.67 percentage increase in wind power production, holding all else constant. The estimated size of the control variables first added in Model 3 remains about the same in Model 4. The statistically significance level, on the other hand, has changed regarding the electricity price, economic activity, and electricity use. By including the extra control variables in Model 4, they contribute to capture some of the variance in the dependent variable, which enables a better understanding of the explanatory variables in interest.

The estimated coefficient for quotas remains statistically insignificant in Model 4 despite an increased coefficient size compared to Model 3. A possible explanation for the change in the coefficient is that it was negatively biased in Model 3 and likely underestimated due to the omitted variable of number of wind power plants, since there is a rather high negative correlation between these two variables (see Appendix A.5). However, since the coefficient for quotas varies between the regressions and remains insignificant, it is hard to draw any precise conclusions.

The estimated coefficient for certificate price remains about the same in Model 4 compared to Model 3, and is still insignificant. The impact on wind power production due to one SEK increase in the certificate price, holding all else constant, is according to the estimated model:

$$\frac{\partial \,\mathrm{Ln}\, Wind\ Power\ Production}{\partial\ Certificate\ price} = (-0.00102)100 = -0.102\ \% \qquad (3)$$

As stated from equation (3), the approximate impact would be 0.102 percentage decrease in wind power production. However, since the certificate price is positively biased due to the omitted variable of certificate surplus, the estimated impact is likely larger than the true effect. The results should therefore be interpreted as slightly overestimated. In conclusion, the results associated with the certificate price are separated from the alternative hypothesis of Hypothesis 1, since the estimated partial impact on wind power production is insignificant. Therefore, we fail to reject the null hypothesis of Hypothesis 1 and are further not able to conclude that the variation in certificate price has an effect on wind power production.

As previously mentioned, the time from a decision of investing, to actual wind power production can often be lengthy. The effects of the variables may therefore be delayed. For instance, a period of high certificate prices may get investors interested in investing in wind power. However, since it takes time to install wind power plants, an increased production of wind power will not immediately be observable. The results in Model 4 may thus be misleading, due to delayed effects. For that reason, we have tested whether lagged versions of certificate price, oil price, votes for the green party, interest rate, electricity price, and economic activity are significant for the model, which results are presented in Table 3. We chose these variables because they are expected to have a delayed effect on wind power production, as a change in wind power production may not be immediately observable if any of the variables change. The variables are lagged two, three, four, and five years and then the logarithmic form of total wind power production is regressed on the lagged variables. Furthermore, the lagged variables have the same unit as in their original form. The only change is that they now are able to capture delayed effects, as they have been lagged.

As can be seen in Table 3, oil price, interest rate, and electricity price are found to be significant at various lagged levels. These significant variables are then included in Model 4, which can be found in Appendix A.7. However, when including these variables, all variables except the three years lagged interest rate are insignificant and therefore, only that variable is included in Model 5. There can be several reasons for why most of the lagged variables became insignificant when included in Model 4. To begin with, the number of observations is comparatively small when lagged variables are included. A small sample size decreases the possibilities to make statistical inference and getting reliable results, especially since the asymptotic assumptions are based on having a large sample size (Wooldridge, 2014). Another reason for the insignificant variables could be heteroskedasticity, non-stationariy processes, serial correlation or highly correlated variables. However, as mentioned in Appendix A.7, tests indicate that there are no such problems in the model. An additional reason for the insignificant variables is that they may have been overestimated from the beginning in the regressions in Table 3, due to the fact that we estimated the lagged variables alone as explanatory variables. That way, they are probably suffering from omitted variable bias, due to omitted variables in the error term. Consequently, the most likely reasons for the insignificant variables are too few observations combined with potential omitted variable bias.

Variables	**Certificate price**	**Oil price**	**Votes for the Green Party**	**Interest Rate**	**Electricity price**	**Economic activity**
2 years lag	0.000937 (0.00102)	-0.00151 (0.00152)	-0.0996 (0.171)	-0.376 (0.269)	0.000529*** (0.000171)	0.00400 (0.00514)
3 years lag	-0.000569 (0.00123)	0.00157 (0.00172)	-0.0160 (0.247)	-0.557** (0.266)	0.000413** (0.000197)	-0.00376 (0.00520)
4 years lag	0.000530 (0.00123)	0.00334* (0.00169)	0.239 (0.281)	-0.289 (0.268)	0.0000866 (0.000227)	0.00254 (0.00519)
5 years lag	-0.00191 (0.00122)	0.00239 (0.00151)	0.322 (0.315)	-0.368 (0.266)	0.000440 0.000276)	0.00320 (0.00530)
Time trend	0.0285*** (0.00182)	0.0231*** (0.00276)	0.0262*** (0.00115)	0.0259*** (0.00108)	0.0249*** (0.00151)	0.0264*** (0.00112)
Monthly dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-11.19*** (0.807)	-8.433*** (1.423)	6.047*** (0.0794)	6.050*** (0.0756)	-9.834*** (0.828)	-10.13*** (0.714)
Observations	79	79	78	78	79	79
R-squared	0.933	0.926	0.9147	0.9249	0.933	0.919

Table 3: Significance test of lagged variables. Standard errors in parentheses. *** indicates significance at 1% level, ** at 5% and * at 10%

When including the three years lagged variable of interest rate in Model 5, it is significant at ten percent level and it also shows a negative sign, which corresponds to the predicted impact based on economic theory. This seems reasonable, since when interest rate increases, investments get more expensive and thus, the investments in wind power plants are expected to decrease. However, the number of observations in Model 5 is smaller than in the previous models, due to the included lagged variable. As previously mentioned, a small sample size decreases the possibilities to make statistical inference and getting reliable results and thus, we have to keep in mind that Model 5 for this reason may be misleading. We will further discuss the three years lagged variable of interest rate in the discussion part.

As can be seen in Table 2, some of the other variables change when the lagged variable is included in Model 5. For instance, the variables representing electricity price and number of wind power plants become insignificant. Furthermore, the sign associated with number of wind power plants has changed to a negative one. The reason for this may again be that there are too few observations. Comparing the other variables in Model 5 with those in Model 4, they have remained more or less the same. The variable representing interest rate without lags is however still significant for the model, and indicates an increase in wind power production as the interest rate increases. Since this is contrary to the predicted impact and economic theory, it is hard to draw any conclusions from this result.

The variables representing certificate price and quotas are still not significant for the model. On the other hand, the expected result would rather be that the effect of the certificate price would be delayed, due to the lengthy process of installing wind power plants. This is why the lagged versions of the certificate price are tested, which is also stated in Hypothesis 2. The results can be found in Table 3. We found that the lagged versions of the certificate price are insignificant for the model, and we fail to reject the null hypothesis of Hypothesis 2. In other words, we fail to find a significant impact of the lagged variables for certificate price on wind power production. Nevertheless, the result that the lagged versions of certificate price are found to be completely insignificant is still odd, since it does not apply to the predicted impact. We will therefore discuss this result in the discussion.

The R-squareds presented in Table 2 measure the goodness-of-fit for the different regressions. It is a measure for how much of the variation in the dependent variable that can be explained by the regressions, where zero indicates that none of the variation can be explained and one indicating that all of the variation can be explained (Wooldridge, 2014). Before the R-squareds were computed we had already detrended the dependent variable. That way, they better reflect how well the explanatory variables explain the variation in wind power production since it nets out the effect of the time trend. Otherwise, the R-squared would be misleading as a measure considering the time trend in the dependent variable. Applying this measure to the regressions, we can see that the goodness-of-fit is increasing as additional explanatory variables are added. This indicates that the explanatory variables contribute to explain the variation in the dependent variable. However, the increase in R-square between Model 3 and 4 is small, indicating that the extra variables actually did not help explaining the dependent variable that much.

5. Discussion

To connect the empirical results to our research question and hypotheses, we will further discuss how the certificate price is indicated to affect production and investments in wind power. Our purpose was to examine whether there exists an impact of the certificate price on the amount of wind power produced. Therefore, we will in the discussion include how factors such as volatile certificate prices and regulation uncertainties might affect investments in wind power.

Based on the results in the five models in our empirical analysis, there is no evidence of an impact on the wind power production due to the certificate price. Hence, we fail to reject our null hypothesis of Hypothesis 1. Additionally, we have to take into account that the estimated coefficient for the certificate price likely is overestimated, due to the omitted variable of the certificate surplus. As mentioned in the result section, the true economic impact is thus likely smaller than the estimated coefficient. Furthermore, since neither of the variables for the TGC system, certificate price or quotas, are statistically significant, there is no evidence of an increased wind power production due to the system. Due to the lengthy implementation process of wind power plants, we further tested for the possibility that the effect of the certificate price on wind power production could be delayed. We chose to examine whether the lagged versions of the certificate price for two, three, four and five years are significant. However, the lagged variables for certificate price are found to be insignificant (see Table 3), and thus we fail to reject the null hypothesis of Hypothesis 2 as well. As mentioned in the result section, possible explanations could be that the sample size is rather small or that the delayed effect is even longer than five years. However, testing further lagged variables was not feasible due to the restricted data available for certificate price, since the number of observations would be too few.

The fact that we failed to reject the null hypotheses, both from Hypothesis 1 and 2, is however not too unexpected. Previous research has indicated that the TGC system has some shortcomings regarding the uncertain and varying certificate price. We had thus suspected that the certificate price could not explain the variation in wind power sufficiently. Moreover, the results are consistent with Carley's (2009) findings, where the corresponding RPS policy is indicated to be insignificant for explaining the renewable energy share of electricity. Even though our model has some problems, such as omitted variable bias and a rather small number of observations on the lagged variables, the results are still consistent with previous research.

This indicates that the results still can be useful to interpret and discuss further. Furthermore, the three years lagged version of interest rate is significant and indicates to have a negative impact on the wind power production, in response to an increased interest rate. This is consistent with the predicted impact, as when interest rate increases investments get more expensive and thus, the investments in wind power plants are expected to decrease. Thus, it is possible that a decreased interest rate could compensate for uncertain certificate prices and hence, increase the incentives for investors to invest in wind power production. Since the significance and sign are consistent with economic theory, it further supports the credibility of our econometric model.

After the implementation of the TGC system, the electricity production generated from renewable resources has in fact increased, which potentially could be a reason for why the certificate price has started to decline. Even though the quotas are designed to prevent decreasing prices, they are set beforehand and hence, they could not predict how much the renewable electricity production would increase. If the increased supply of certificates is not met by an increased demand, the result will according to economic theory be lower prices. Consequently, this could also be a reason for the decreased prices. This is a situation of reverse causality, since the certificate price is being affected by the amount of wind power produced.

The fact that the certificate price is found to be insignificant could be explained by results from previous research about how uncertain and volatile certificate prices are found to refrain investors from investing (Blomqvist et al., 2008; Dinica, 2006; Klessmann et al., 2008). Since the certificate prices are considered to be volatile, combined with regulatory changes in the TGC system, such as Norway joining the market, the whole TGC system can thus be considered to be rather uncertain. The uncertainties combined with lengthy investment processes, might indicate that the actual certificate prices have a small effect on investment decisions. For instance, there is no way of knowing, at the time of the decision of investing, what the certificate price will be in the future. It is therefore hard for investors to calculate exactly how much extra revenue they will get from selling certificates in addition to the electricity price. Consequently, a high certificate price at the time of the decision of investing is no guarantee that the price will stay high. This could therefore be an additional explanation of why neither the certificate price nor the lagged certificate price are found to be significant.

Assuming, for instance, that the delayed effect is about seven years due to the lengthy investment processes, a high certificate price today would not be observable until seven years ahead. By studying the development for the certificate price in Figure 3, it is possible to see a peak in the price in 2008-2009, about six to seven years ago. Since the price was high and thus possible revenues as well, it can be assumed that many chose to invest at that time. Furthermore, the TGC system was relatively new at that time, and the uncertain and varying price may not have been as observable as today. Hypothetically, as the certificate price six years ago started to decrease, this would imply that the exponential increase in wind power production soon will start to decline. As earlier mentioned, the Swedish Energy Agency (2014b) recently discovered a tendency in decreased interest for wind power investments, which supports this argument.

Even though the wind power production has increased in Sweden after the implementation of the TGC system, it has not increased as much as in, for instance, Denmark. This is despite the fact that Sweden has substantial developing potentials and highly favourable wind conditions. According to Klessmann et al. (2008), investors will require higher expected returns on their investments when there are uncertain revenues. Consequently, the uncertain TGC system combined with investors requiring higher expected returns could be a reason for why Sweden still has a comparatively small share of wind power production. Moreover, the fact that the interest for investing in wind power production has started to decrease (Blomqvist et al., 2008) also support this argument. The decreased interest in investing could also be an indication of investors needing a more stable system in order for Sweden to reach the high potential of wind power production in the future. It is further argued by Dinica (2006) that it would be preferable if investors could be able to predict their revenues on a more long-term basis.

Finally, testing whether changes in the certificate price may have a delayed effect on investments in renewable energy production, have to our knowledge never been done before. This is something that we find strange, since it is not possible that a change in the certificate price today can have observable effects at the same time. However, previous research has focused on the share of the total renewable energy production and thus, has not been concentrated to wind power production. It is possible that other renewable energy resources are easier to install, such as solar power. This would mean that a change in the certificate price could have an observable effect much faster than with wind power, which has a lengthy instalment process.

6. Conclusion

The share of wind power production in Sweden is still comparatively small, despite the increased production and the great potentials. Furthermore, the interest for investing in wind power production has started to decrease lately. The main objective of this thesis was therefore to examine if there exists an impact of the certificate price on the amount of wind power produced. To examine this, we stated two hypotheses to test both the current effect and the possible delayed effect, and then made five regressions to test them. The results were consistent between the regressions and indicated no impact of the variation in certificate price on wind power production, neither current nor delayed effects. However, the results are in line with previous research in which some shortcomings of the TGC system has been found, such as uncertain and varying certificate price. Additionally, the results are consistent with a similar empirical study, indicating that our results are credible even though our model had some weaknesses, such as possible omitted variable bias and a rather small number of observations of the lagged variables. A possible explanation for the insignificance could also be that the delayed effect is even longer than what we were able to measure. Therefore, it would be interesting to do further research on this subject once the system has been in place for a longer time since more data then will be available.

As the results indicate that the actual price of certificates are found to be insignificant to the development of wind power, other explanations had to be examined. Previous studies suggest that with uncertain and varying certificate prices investors tend to require higher expected returns and thus not investing as much as what could be possible. Another shortcoming of the TGC system is that as the renewable energy production increases, the supply of certificates increases as well. The quotas are set to increase the demand for certificates as the supply increases. However, as the quotas are set beforehand it does not correspond to the actual increase in supply, leading to an increasing certificate surplus. Thus, as the supply is greater than the demand, the certificate prices are expected to decrease. The uncertainty of future certificate prices will thus probably decrease the incentives to invest in wind power. In conclusion, the TGC system as a policy instrument could be argued to be somewhat inefficient. Future research could therefore be to examine whether a more stable system could increase the interest for investing in wind power. An example of such system could be to include a certificate price floor, which would guarantee investors a certain payment. This would thus decrease the risk, and the wind power potentials in Sweden could possibly be fulfilled.

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Appendix

A.1 Descriptive statistics

Variables	**Obs**	**Mean**	**Std. Dev**	**Min**	**Max**
Certificate price	139	221.4	47.08	110.9	330.4
Quotas	139	14.263	3.436	7.4	17.9
Green Party Votes	139	7.055	2.221	4.1	11.7
Electricity use	139	11,885	2,068	8,522	16,464
Interest rate	139	1.815	1.181	0	4.75
Oil price	139	76.87	26.94	26.90	132.5
Electricity price	139	363.2	124.0	122.1	926.0
Economic activity	139	0.925	4.761	-17.88	18.72
Number of wind power plants	127	118.3	55.34	55.58	220
Wind Power Production	139	339.1	338.0	24	1,607

Table 4: Descriptive statistics of the variables in its original form, before any transformations are made. *Obs* refers to the number of observations, *Mean* to the arithmetic mean, *Std. Dev* to standard deviation, *Min* to minimum value, and *Max* to maximum value.

A.2 Test for heteroskedasticity

To test for heteroskedasticity, the Breusch-Pagan test is used on Model 4 in Table 2. The null hypothesis is homoscedasticity, meaning constant variance in the residuals. The test statistic, chi2, is 0.58 and the p-value is 0.4480. The null hypothesis can therefore not be rejected, which indicates homoscedasticity.

A.3 Test for serial correlation

To test for serial correlation, the Durbin-Watson test is made on Model 4 in Table 2. The Durbin-Watson d-statistic for 12 estimated variables and 126 observations is 1.900974. In the significance table for 12 estimators, and choosing 100 as sample size (a lower value than the actual observations is chosen to be on the safe side), the lower limit is 1.462 and the upper limit is 1.898. Since the tested value is higher than the upper critical limit, there is no evidence of positive first order serial correlation in the model.

A.4 Stationarity

ADF test	**t-statistic**	**p-value**	**Lags**
Certificate price *(Original)*	-2.041	0.2688	13
Certificate price *(First difference)*	-3.737	0.0036	13
Quotas (*Original)*	-2.345	0.1578	13
Quotas *(First difference)*	-3.511	0.0077	13
Green Party Votes *(Original)*	-1.283	0.6371	13
Green Party Votes *(First difference)*	-3.570	0.0064	13
Electricity use *(Original)*	-1.180	0.6820	13
Electricity use *(Detrended & Seasonally adjusted)*	-3.302	0.0148	13
Interest Rate *(Original)*	-2.010	0.2821	13
Interest Rate *(First difference)*	-3.181	0.0211	13
Oil price *(Original)*	-2.062	0.2599	13
Oil price *(Detrended)*	-3.535	0.0071	13
Electricity price *(Original)*	-2.044	0.2676	13
Electricity price *(First difference)*	-3.764	0.0033	13
Economic activity *(Original)*	-3.088	0.0275	13
Number of wind power plants *(Original)*	-0.602	0.8705	12
Number of wind power plants *(Detrended)*	-3.015	0.0335	12
Ln Wind Power Production *(Original)*	0.213	0.9730	13
Ln Wind Power Production *(Detrended)*	-2.981	0.0367	13

Table 5: Statistics for the Augmented Dickey-Fuller (ADF) test.

Low p-values of the ADF tests indicate that we can reject the null hypotheses of a unit root and that the time series are stationary processes. As seen in the table, we can reject the null hypothesis of a unit root for one version of all of the variables on at least five percent significance level. The italic text in the parentheses is clarifying the form of the variables. For instance, the ADF test for the certificate price in its original form indicated a unit root. However, in the first differenced form of the certificate price we can reject the null hypothesis of a unit root at one percent significance level and thus, we chose to use that variable. The chosen lag length is determined by Schwert's criterion (1989).

A.5 Correlation matrix

	Windpro	Certpr	Quota	Votes	Rate	Oilpr	Eluse	Elpr	Ecoact	Nowind
Windpro	1									
Certpr	-0.0421	1								
Quota	0.1684	0.0246	1							
Votes	0.0189	0.1538	0.1123	1						
Rate	0.069	0.0032	0.0424	0.0458	1					
Oilpr	-0.0941	0.0381	-0.0798	-0.0698	0.2538	1				
Eluse	0.5583	0.0053	0.1749	0.1646	-0.0113	-0.113	1			
Elpr	-0.0996	-0.0828	-0.0424	0.1763	0.1169	0.1798	0.1996	1		
Ecoact	-0.0313	0.1112	-0.0633	-0.1677	-0.1505	-0.3169	0.1053	-0.1269	1	
Nowind	0.2372	-0.048	-0.1974	-0.075	0.0027	0.1123	-0.0456	-0.1763	0.026	1

Table 6: The correlation between variables used in Model 4 in Table 2.

The names in the correlation matrix are abbreviated and to clarify, a list of the names follows:

Windpro = Wind Power Production
Certpr = Certificate price
Quotas = Quotas
Votes = Votes for the Green Party
Rate = Interest rate
Oilpri = Oil price
Eluse = Electricity use
Elpr = Electricity price
Ecoact = Economic activity
Nowind = Number of wind power plants

The strongest correlation is observed between wind power production and electricity use, which is 0.5583. However, it should not be a problem since the high correlation is between an explanatory variable and the dependent variable (Wooldridge, 2014). The rest of the correlations indicate no sign of perfect collinearity between any of the explanatory variables.

A.6 Test for time trend and seasonality

To test for a time trend, the logarithmic Wind Power Production variable is regressed on a time trend. The estimated time trend is 0.0194 and is found to be significant at one percent level, which indicates evidence for a positive time trend. To test for seasonality, so called dummies are generated for each month. For instance, for January the dummy is equal to one if the month is January and zero if it is any of the other months. The dependent variable, Wind Power Production, was then regressed on 11 of the dummies. Thereafter, an F-test was made, in which the F-value was 11.03 and the p-value was 0.000, which indicates that the null hypothesis of no seasonality can be rejected at one percent significance level. Hence, the monthly dummies are jointly significant for the model. Consequently, both a time variable and monthly dummies should be included in the model to adjust for a time trend and seasonality.

A.7 Model 4, including significant lagged variables

Variables	**Including lagged significant variables**
Certificate price	-0.000757 (0.00158)
Quotas	0.0351 (0.0577)
Electricity price	-0.0000181 (0.000352)
Economic activity	-0.00981 (0.00653)
Elelctricity use	-0.000144** (7.13e-05)
Inerest rate	0.219* (0.117)
Votes for the Green Party	0.00729 (0.0569)
Oil price	-0.000861 (0.00230)
Number of wind power plants	0.00170 (0.00722)
Oil price 4 years lagged	0.000232 (0.00174)
Interest rate 3 years lagged	-0.199* (0.116)
Electricity price 2 years lagged	0.000214 (0.000281)
Electricity price 3 years lagged	0.000111 (0.000293)
Time trend	0.0239 (0.0150)
Monthly dummies	Yes
Constant	-6.800 (8.427)
Observations	79
R-squared	0.929

Table 7: Standard errors in parentheses. *** indicates significance at 1% level, ** at 5% and * at 10%. Test of the model with the included lagged variables shows homoskedasticity, stationary processes and no serial correlation. Furthermore, a correlation matrix show no high correlation between any of the variables.