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The role of regulatory uncertainty in certificate markets: A case study of the Swedish/Norwegian market

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HIGHLIGHTS

- Paper analyzes the impact of regulatory changes on certificate price volatility.
- Regulatory changes affect market volatility and price risk.
- Regulatory uncertainty harms certificate markets.
- The bigger Swedish/Norwegian market has not resulted in lower volatility yet.

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ABSTRACT

Price volatility in green certificate markets reflects uncertainty over future prices, representing a major source of risk for renewable energy generators. Price risk is considered the principal deficiency of this market-based policy since it causes investors to require higher returns. Moreover, investors are exposed to regulatory risk; namely, the risk that a change in the regulation will materially impact the certificate price. Regulatory uncertainty is reflected in market volatility exacerbating certificate price risk. Using an econometric approach, we investigate the role of regulatory changes on price volatility in the Swedish certificate market. The results of our analysis indicate that regulatory changes strongly affect certificate markets, resulting in periods of higher volatility. Moreover, we analyze whether certificate price volatility has changed after creating a joint Swedish/Norwegian market. Results indicate that the ambivalence surrounding the creation of this bigger market led to a period of increased price volatility between 2010 and 2011. Overall, this article brings a better understanding of the role of regulatory uncertainty on certificate markets, and gives evidence for its negative impact in terms of increased price volatility.

1. Introduction

In the last two decades renewable energy sources (RES) have received increased support from national governments. Directive 2009/28/EC of the European Commission indicates that RES has to provide at least 20% of the European Union gross final energy consumption by 2020. The EU motivated this decision announcing that an increased use of RES is necessary to reduce greenhouse gas emissions complying with the Kyoto protocol. Furthermore, RES can improve security of energy supply, foster technological advancement and provide development of rural areas.

Tradable certificate markets, also known as green certificate markets, became of interest in Europe in the early 2000s after the liberalization of electricity markets. A tradable certificate market is a policy mechanism aiming to support electricity production from RES. Green certificate mechanisms were introduced in Italy, the United Kingdom, Sweden, and Belgium between 2001 and 2003. The mechanism functions with regulatory imposition of a quota for a certain amount of the electricity consumed to be produced by RES, issuing certificates to generators offering renewable electricity. Parties having a quota obligation, usually retailers or distributors, regularly surrender certificates to the regulator corresponding to their quota, incurring in a penalty fee for each certificate they are short of. Hence, obliged parties can decide to either buy certificates from existing generators, or to build power plants and produce certificates on their own. This way, the regulator creates a market mechanism in which the price paid for renewable electricity is determined by the interaction between certificate demand and supply.

Theoretically, a certificate market should obtain the desired amount of renewable electricity cost-efficiently, attracting investments in less expensive technologies through competition. Furthermore, there is an incentive for generators to limit their

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operating cost being continuously exposed to market competition (Menanteau et al., 2003). However, market-based mechanisms have received much criticism since their introduction in Europe. First of all, it is argued that by guaranteeing the same price to different technologies, certificate markets distribute windfall profits to less expensive technologies at the expense of cost-efficiency (Haas et al., 2010). Through analyzing the cost of the Swedish market it appears that generators are not currently benefitting from windfall profits due to higher marginal prices. Nonetheless, windfall profits were created by including a number of existing generators in the system in order to ensure enough liquidity in the initial phases of the market (Bergek and Jacobsson, 2010).

A far more critical issue is posed by the volatility of certificate prices. Indeed, analysis illustrates that certificate prices could be highly uncertain and volatile, exposing electricity companies to high price risk. Certificate price volatility can be caused by the long lead time for construction of new power plants. In fact, new investments in reaction to high prices may not arrive in time to prevent a prolonged period of certificate shortages. Moreover, high certificate prices could trigger an over-reaction by investors, causing a period of very low or null prices. This would lead to investment cycles in renewable energy technologies causing very volatile prices (Ford et al., 2007). Renewable energy projects are capital intensive and, excluding biomass-fired plants, exhibit almost null marginal cost. Thus, in case of over-investment in the renewable sector, the certificate price would collapse causing massive capital losses to investors (Kildegaard, 2008). Price volatility could be further exacerbated by the variations of natural resources from year to year. Due to high price uncertainty and the little maturity of these markets, investors could perceive projects supported through a certificate market as too risky (Dinica, 2006; Gross et al., 2010). To compensate for the higher perceived risk, investors will require higher expected returns on renewable energy projects, leading to under-investment and higher certificate prices (Klessman et al., 2008). Certificate price volatility may be considerably reduced by allowing suppliers and consumers to bank certificates to comply with future quota requirements (Amundsen et al., 2006).

Certificate markets are characterized by a politically driven demand, causing investors to be heavily exposed to regulatory uncertainty (Holburn, 2012). Political changes can harm investors, making it more difficult to estimate future revenues and costs, thus decreasing the willingness to invest in new renewable energy projects (Soderholm, 2008). For example, a change in the quota levels or a different allocation of certificates to generators, could lower the profitability potential, or decrease the economic profitability of renewable energy projects. Changes in the regulation can have an impact on certificate prices, price volatility and risk, ultimately affecting the cost of financing a project (Gross et al., 2010). Similarly to how political instability can increase the volatility of equity markets (Brown et al., 2006), regulatory uncertainty is reflected in certificate price volatility. As such, price stability is an important determinant of the performances of a certificate market mechanism, in turn making the analysis of how regulatory risk affects market volatility worthwhile.

Previous studies analyzed certificate markets predominantly using numerical modeling frameworks or ex-post case studies analyses. For example, Morthorst (2000) studies the long-run equilibrium of certificate markets arguing that the price could become highly volatile due the fluctuations of RES and the inelasticity of certificate demand. Menanteau et al. (2003) compare theoretically the performances of different renewable energy policies analyzing the pros and cons of price and quantity-based approaches. Mitchell et al. (2006) compares the renewable obligation imposed in England with the German feed-in tariff, arguing that the latter is more effective due to the lower risk involved for generators. Amundsen et al. (2006) take the analysis of Morthorst (2000) a step further suggesting that certificate banking may limit price volatility. Dinica (2006) investigates the performances of support schemes for RES from the perspective of investors and indicates that it is not the type of instrument but rather its risk-profitability characteristics that determine policy performances. Ford et al. (2007) simulate the price dynamics of a certificate market designed to support wind generators using a system-dynamic approach, reaching to the conclusion that such a market will experience investment cycles and high price volatility. Agnolucci (2007) investigates short-term dynamics of certificate markets arguing that this type of mechanism may attract few investors due to pessimistic price expectations. As a solution, the author stresses the importance of long-term contracts for a certificate market to be effective. Kildegaard (2008) indicates that in a certificate market where high fixed-cost technologies are predominant, long term contracts represent a Nash equilibrium situation for producers and consumers. On the other hand, this is not the case when low fixed-cost technologies such as biomass-fired generators exist in a sufficient quantity. Klessman et al. (2008) analyze the pros and cons of exposing renewable energy investors to market risk, taking Germany, Spain and the United Kingdom as case studies. Amundsen and Nese (2009) investigate the performances of certificate markets of the Swedish type when integrated within several countries, using both an analytical and a partial equilibrium model. One of their main conclusions is that the quota requirement is not a very precise policy measure to stimulate green electricity generation. Bergek and Jacobsson (2010) investigate the efficiency of the Swedish certificate market during the period 2003–2008 claiming that its cost for consumer was higher than expected and that the system has generated large rent to existing generators. Gross et al. (2010) argue that policy makers should consider the impact of revenues risk on investors instead of taking decisions simply based on levelized cost calculations. Amundsen and Bergman (2012) study market power in the Swedish certificate system and how this could affect the electricity market. Their analysis shows how the creation of a bigger Scandinavian market would prevent Swedish producers from exercising market power. Fagiani et al. (2013) compare the performances of feed-in tariffs and certificate markets concluding that investors' risk-aversion negatively affects the performances of a certificate mechanism.

To our best knowledge, no prior study has investigated empirically the impact of regulatory uncertainty on certificate price volatility. More specifically, this paper aims to answer the following research question: What is the impact of regulatory changes on certificate price volatility? As a case study we focus on the Swedish certificate market which was introduced in 2003. Almost 10 years after its creation, the Swedish market has become the first multi-national market of this kind in January 2012, when Norway joined the mechanism. This collaboration gives European policy makers the opportunity to verify the behavior of international certificate markets, which may represent a model for the EU as a whole.

A bigger joint Swedish/Norwegian market is expected to increase liquidity and competition by increasing the number of market participants (Swedish Energy Agency, 2012). Also, a joint market with Norway will stimulate investments in cheaper wind power plants in Norway, where wind conditions are better, lowering the cost burden of the quota system on Swedish consumers (Soderholm, 2008). Moreover, an international market guarantees a diversification of RES that could mitigate the fluctuation of certificate supply compared to a smaller national market, providing certificate price stability (Del Rio, 2005). However, a bigger market is also expected to decrease the market power of Swedish producers (Amundsen and Bergman, 2012), consequently increasing the volatility of certificate prices (Gross et al., 2010). Hence, this analysis also investigates the following research question: What is the impact of the creation of a joint Swedish/Norwegian certificate market on certificate price volatility?

For the scope of this research we develop an econometric analysis of the Swedish certificate market using the generalized autoregressive conditional heteroskedasticity (GARCH) methodology. The GARCH model is one of the most widely used to investigate volatility characteristics of time series (Engle, 1982; Bollerslev, 1986). GARCH models assume no constant variance allowing for volatility clustering, namely the characteristic that large changes tend to be followed by large changes, of either sign, and small changes tend to be followed by small changes. For this reason a large volume of literature has modeled price volatility in financial and commodity markets using GARCH models. For example, Bollerslev et al. (1992) and Brailsford and Faff (1996) investigate volatility in financial markets. West and Cho (1995) and McKenzie and Mitchell (2002) analyze currency exchange rates. More recently, Sadorsky (2006) models the volatility of petroleum future prices, Oberndorfer (2009) investigates the interactions between the EU ETS and the stock market, while Paolella and Taschini (2008), Alberola et al. (2008), and Benz and Stefan (2009) study the price dynamics of CO_2 emissions allowances in the EU ETS.

We implement an endogenous structural break test to detect changes in the unconditional variance of the Swedish certificate price (Inclan and Tiao, 1994; Sanso et al., 2004), investigating the correspondence between structural breaks and changes in the regulation. This test has been used to study changes in the volatility of U.S. exchange rates (Rapach and Strauss, 2008), oil price (Ewing and Malik, 2010), and commodity markets (Vivian and Wohar, 2012). Also, Chevallier et al. (2011) implement this endogenous structural break test to investigate the impact of introducing option trading on the volatility of the EU ETS.

After testing for structural breaks, we estimate a GARCH model with dummy variables to analyze the impact of regulatory changes on the volatility of certificate price (Chevallier et al., 2011). Our analysis indicates that the Swedish certificate market entered a regime of higher volatility from the beginning of 2010 to the end of 2011. Volatility was caused by the ambiguity surrounding an increased quota regulation and the creation of a joint market with Norway, and resolved after the two countries agreed on the creation of a common market. Interestingly, the bigger market has not led to a significant decline in volatility compared to past levels, yet.

Overall, this analysis contributes to better understanding the role of regulatory uncertainty in certificate markets, being of interest for both policy makers and potential investors. The remainder of the paper is organized as follows. Section 2 presents the Swedish certificate market and resumes the regulatory changes that characterized it. Section 3 describes the data sample used for this study. Section 4 summarizes the econometric methodology. Section 5 presents the estimation results of our analysis. Finally, Section 6 concludes with outcomes and recommendations.

2. From the creation of the Swedish certificate system in 2003 to the establishment of a joint market with Norway in 2012

Sweden introduced a certificate market mechanism to stimulate electricity production from RES in May 2003. Electricity producers whose electricity production fulfills the requirement of the Electricity Certificate Act receive one certificate for each MWh of electricity generated. Demand for certificates is created by obligating electricity suppliers and some consumers to purchase certificates corresponding to a certain proportion (quota) of the electricity they sell and consume. Suppliers are required to submit every year no later than March 1st an annual return to the Swedish Energy Agency with the details of the electricity sold and consumed in the previous years and the certificates corresponding to their quota obligation. Obliged parties holding insufficient certificates to comply with the legislation are charged a penalty price for each certificate they are short of, corresponding to 150% of the average certificate price of the previous year. Through the sales of certificates, electricity producers receive an extra source of revenue integrating the income deriving from the electricity market. As a result, the certificate market stimulates investments in renewable energy generators.

Apart from the first year of the system, the proportion of canceled certificates in relation to the overall quota obligation has been constantly over 99%. Market liquidity is guaranteed by a buffer of banked certificates which absorb annual fluctuations of demand and supply avoiding period of scarcity in the market. Importantly, policy makers review the system every 4 years deciding to adjust the size of the quota to take into account actual and forecasted electricity demand, capacity expansion, and the size of the certificate surplus.

Half of the certificates are traded through bilateral agreements or directly between producers and those having quota obligations, with the other half traded through brokered transactions. The most liquid trading is in forward contract for the following March and spot contracts, each of which account for about one third of total traded volumes. In order to improve the liquidity of the certificate market during its initial phase, certain existing generators were initially included in the system. These power plants were entitled to receive certificates until the end of 2012 at the expense of electricity consumers (Bergek and Jacobsson, 2010). However, liquidity is of extreme importance in order for the market price to be regarded as reliable, and has progressively improved with increasing quota obligations (Swedish Energy Agency, 2012).

The quota requirement is constantly raised from year to year, increasing certificate demand. Initially the objective of the system was to increase by 2010 the production of electricity from RES by 10 TWh relative to the production level of 2002. In 2004, the object of the mechanism was extended including the production of electricity from peat as a fuel in combined heat and power (CHP) plants. In January 2007 the mechanism's target was increased to achieve 17 TWh of additional renewable electricity by 2016, relative to the corresponding production of 2002 (Swedish Energy Agency, 2007). On the 16th of June 2009 the Swedish parliament decided that the target of the certificate mechanism should have further risen in order to comply with the EU Renewable Energy Directive proposal adopted on September 17th, 2008 (Swedish Energy Agency, 2009). Consequently, on the 10th of March 2010 the government presented ‘The electricity certificate system: higher target and further development’ bill, which proposed to extend the certificate mechanism until 2035. The bill also proposed to adjust the quota obligation to the new target of renewable electricity production, which involved an increase of 25 TWh by 2020 compared to the levels of 2002. Moreover, the government presented, together with the bill, an assessment indicating that the certificate system should have included more countries, aiming to establish a common certificate market with Norway from January 2012 (Ministry of Enterprise, Energy and Communications, 2010a). The new quota was approved by the Swedish parliament on July 1st, 2010 (Swedish Energy Agency, 2011).

Successively, the Swedish and the Norwegian governments signed a protocol to create a common certificate market on the 8th of December 2010. The new market would have started in January 2012 aiming to provide 26.4 TWh of electricity from RES by 2020 in addition to the 25 TWh Swedish target. The final agreement between the two countries was signed in Stockholm on the 29th of June 2011, and the joint-mechanism will be effective until 2035 (Ministry of Petroleum and Energy, 2011). The Swedish parliament finally approved the bill no. 2010/11:155 'A new electricity market act – simpler rules and a joint electricity market' on the 30th November 2011 (Riksdag, 2011).

In the Swedish/Norwegian market, certificates can be traded across the countries' border with no differences between certificates issued in the two countries, representing the first example of international certificate market worldwide. Scandinavian policy makers expected a bigger market to lead to improved competition, increased liquidity and more stable prices. Moreover, they expected to achieve renewable energy targets more cost-efficiently since investments will take place where conditions are more favorable between the two countries (Ministry of Enterprise, Energy and Communications, 2010b). No reference was made to the fact that producers' market power could decrease price volatility (Gross et al., 2010), and that a more competitive market could lead to more volatile prices. Within this paper we investigate whether volatility has changed during the analyzed period focusing on the impact of creating a bigger Swedish/Norwegian market.

3. Data

This study develops an econometric analysis of the Swedish certificate market using data from January 1st, 2007 to March 25th, 2013. We gathered a sample of 326 weekly observations from data published online by Svensk Kraftmäkling, Nord Pool and STOXX limited.

3.1. Certificate price

For the certificate price we use the spot price published by Svensk Kraftmäkling, a brokerage firm of the Nordic electricity market. Prices are in Swedish Krona (SEK). The evolution of the spot price and its return between January 2007 and March 2013 are represented in Figs. 1 and 2.

Descriptive statistics of the certificate spot price and its return are presented in Table 1. We observe that the certificate price presents negative excess kurtosis and positive skewness, while the return shows both positive excess kurtosis and skewness. Both the Augmented Dickey-Fuller (ADF) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests indicate that the return of the certificate price is stationary (Said and Dickey, 1984; Kwiatkowski et al., 1978).

3.2. Electricity price

The primary source of revenues for renewable energy generators derives from participating in the electricity market. The certificate price rewards renewable electricity producers for the higher generation cost of renewable energy technologies, and should reflect the difference between the average cost of renewable electricity and the electricity price. For the analysis we use the system day-ahead electricity price in SEK published by Nord Pool Spot, a leading power market in Europe which includes Sweden, Norway, Finland, Denmark, Estonia and Lithuania. The return on the electricity price is presented in Fig. 3. Descriptive statistics of the electricity price return are presented in Table 2. The electricity price return presents positive excess kurtosis and skewness, moreover the ADF and KPSS tests indicate that it is stationary.

Fig. 1. Certificate spot price from January 1st, 2007 to March 25th, 2013.

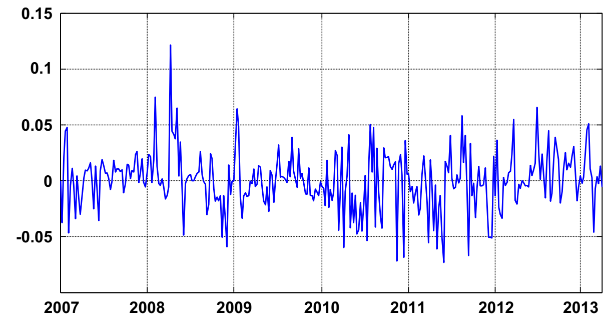

Fig. 2. Return on the certificate spot price from January 1st, 2007 to March 25th, 2013.

3.3. Equity markets

Economic growth has an important role in determining the demand of energy commodities and electricity (Chen et al., 2007; Narayan et al., 2007; Squalli, 2007; He et al., 2010). It has been demonstrated that economic activity also influences the EU Emission Trading System (ETS) price, with economic growth leading to higher carbon prices (Bredin and Muckley, 2011; Creti et al., 2012). Economic growth should also influence certificate demand since it is obtained as a percentage of electricity consumption.

Similarly to Bredin and Muckley (2011) and Creti et al. (2012) we use an equity index as a measure of economic condition. In addition to the fact that this variable reflects financial and economic conditions expectations with the required weekly frequency, it allows considering certificates as a financial asset, controlling for the recent financial turmoil. The variable used for the analysis is the STOXX® Nordic 30 index, which includes 30 stocks of the bigger companies of Denmark, Finland, Iceland, Norway and Sweden. Return on the index price is presented in Fig. 4. Descriptive statistics indicate that the index price return is stationary, with negative skewness and positive excess kurtosis, Table 2.

4. Methodology

GARCH models are often used to investigate the volatility of time series (Engle, 1982; Bollerslev, 1986). GARCH models assume no constant variance, modeling the conditional variance as a function of the mean volatility level, previous period's conditional variance, and information about volatility from the previous period. We intially model the return of the certificate price using the GARCH model presented in

$$
\begin{aligned}
r_t &= \rho r_{t-1} + \varepsilon_t \\
\varepsilon_t &\sim s_t e_t \\
s_t^2 &= \omega + \alpha \varepsilon_{t-1}^2 + \beta s_{t-1}^2 \qquad (1)
\end{aligned}
$$

where r_t is the return on the certificate price, e_t follows a standard normal distribution, s_t^2 represents the conditional variance, and ω is a constant. β, α, and ω must be non-negative to ensure that the conditional variance remains positive. A GARCH process is stationary

Table 1
Descriptive statistics of the certificate spot price and return for the period from January 1st, 2007 to March 25th, 2013.

	Mean	Median	Max	Min	S.D.	Skew.	Kurt.	ADF	KPSS	N
Price	242.59	227.30	376.00	140.00	65.70	0.3572	1.9709	−1.2550	0.8549***	326
Return	0.0004	0.0010	0.1215	−0.0732	0.0255	0.1066	4.8663	−13.5771***	0.2346	325

*Shows significance at 10% level.
**Shows significance at 5% level.
***Shows significance at 1% level.

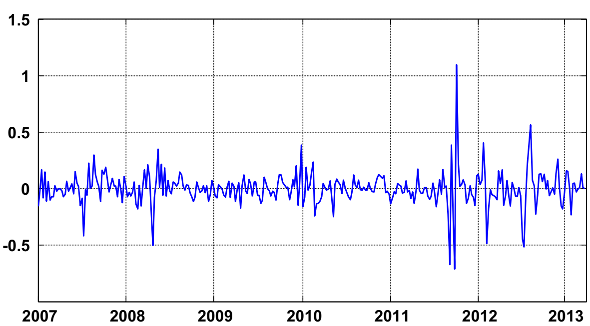

Fig. 3. Return on the electricity price from January 1st, 2007 to March 25th, 2013.

if $\alpha+\beta<1$, in that case the unconditional variance is not time dependent and is given by

$$\sigma^2=\omega/(1-\alpha-\beta) \tag{2}$$

However, the model presented in (1) assumes constant unconditional variance. Instead, for the scope of our analysis, we want to test the null hypothesis of constant unconditional variance against the alternative of a break. The Chow test is often used to test for the presence of structural breaks in time series analysis (Chow, 1960). Unfortunately, this test is designed to test whether the coefficients of a linear regression suffer from a structural break and is not applicable to our case. Instead, Inclan and Tiao (1994) propose the following cumulative sum of squares (*IT*) statistic for testing the null hypothesis of a constant unconditional variance of GARCH models.

$$IT=\sup_k|\sqrt{T/2}D_k| \tag{3}$$

where

$$D_k=\frac{C_k}{C_T}-\frac{k}{T} \tag{4}$$

And C_k is the cumulative sum of squares of ε_t. Under the assumption that ε_t follows a normal distribution with zero-mean, the asymptotic distribution of the test is given by

$$IT\Rightarrow\sup_r|W^*(r)| \tag{5}$$

where $W^*(r)$ is a Brownian bridge:

$$W^*(r)=W(r)-rW(1) \tag{6}$$

$W(r)$ is a standard Brownian motion and $\Rightarrow$ stands for weak convergence of the associated probability measures. If the *IT* statistic is greater than a critical value, the null hypothesis of constant unconditional variance is rejected and the series presents a structural break. Inclan and Tiao (1994) also demonstrate that the *IT* statistic could not detect multiple breaks in variance when examining the entire data series. To avoid this problem, they propose an Iterated Cumulative Sum of Squares (ICSS) algorithm based on the *IT* statistic that control different pieces of the series looking for multiple breaks in the unconditional variance.

Sanso et al. (2004) demonstrate that the *IT* statistic is significantly oversized when used on GARCH processes. In particular, they indicate that the most serious drawback to the *IT* statistic is the fact that its asymptotic distribution is critically dependent on the assumption that the random variable ε_t has a normal, independent and identical distribution. Therefore, they propose a nonparametric adjustment to the *IT* statistic which makes it suitable for GARCH models showing that structural breaks can be accurately detected with their proposed method. These authors present the following adjusted *IT* (*AIT*) statistic:

$$AIT=\sup_k\left|\left(1/\sqrt{T}\right)G_k\right| \tag{7}$$

where

$$G_k=\left(1/\sqrt{\widehat{\omega}_4}\right)\left(C_k-\frac{k}{T}C_T\right) \tag{8}$$

where $\widehat{\omega}_4$ is a consistent estimator of ω_4:

$$\omega_4=\lim_{T\to\infty}E\left(1/T\left(\sum_{t=1}^{T}(\varepsilon_t^2-\sigma^2)\right)\right) \tag{9}$$

Sanso et al. (2004) propose to use a non-parametric estimator of ω_4 which depends on the selection of a bandwidth using an automatic procedure, as for example the Newey and West (1994) procedure. We use the ICSS algorithm based on the *AIT* statistic to detect multiple structural breaks in the variance of the certificate price.

We compare the results of the break test with the regulatory changes of the certificate market to investigate if there is any correspondency between them. Then, we estimate the GARCH model introducing dummy variables in the variance equation of (1) representing the breaks indicated by the endogenous test, as indicated in

$$\begin{aligned}&r_t=\rho r_{t-1}+\varepsilon_t\\&\varepsilon_t\sim S_t e_t\\&S_t^2=\omega+\sum\phi_t D_t+\alpha\varepsilon_{t-1}^2+\beta S_{t-1}^2\end{aligned} \tag{10}$$

Also, we estimate the model using different dummies corresponding to other regulatory changes for the sake of completeness.

Succesively, we compare the estimated coefficients of the GARCH model (10) with those of a Taylor/Schwert GARCH model (Taylor, 1986; Schwert, 1990). The Taylor/Schwert GARCH model was proposed considering the empirical fact that, in many financial series, autocorrelation is greater for absolute than squared returns (Ding et al., 1993). Thus, it models the conditional standard deviation as a linear function of lagged absolute returns, instead of assuming the conditional variance as a linear function of lagged squared returns. See

$$\begin{aligned}&r_t=\rho r_{t-1}+\varepsilon_t\\&\varepsilon_t\sim S_t e_t\\&s_t=\omega+\sum\phi_t D_t+\alpha|\varepsilon_{t-1}|+\beta s_{t-1}\end{aligned} \tag{11}$$

Finally, in order to avoid misspecification of the econometric approach, we introduce electricity and equity index price as explanatory variables in the GARCH model, adding their return

Table 2
Descriptive statistics of the Nord Pool electricity and Nordic 30 index price returns for the period from January 1st, 2007 to March 25th, 2013.

	Mean	Median	Max	Min	S.D.	Skew.	Kurt.	ADF	KPSS	N
Elect.	0.0011	0.0007	1.0983	−0.7113	0.1482	0.5815	15.835	−14.2171***	0.0528	325
Equity	−0.0002	0.0018	0.0970	−0.1375	0.0243	-0.8204	6.9207	−15.9912***	0.1650	325

*Shows significance at 10% level.
**Shows significance at 5% level.
***Shows significance at 1% level.

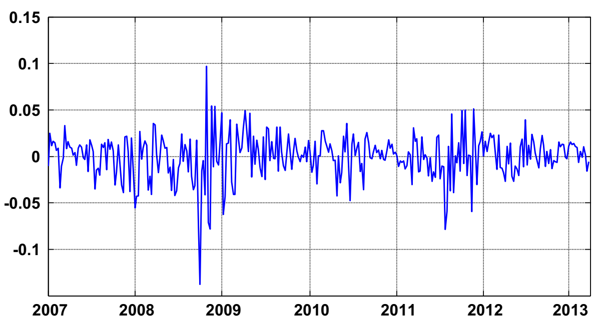

Fig. 4. Return on the equity index price from January 1st, 2007 to March 25th, 2013.

as independent variables to the mean equation of the model. Also, we include their variance in the variance equation, controlling for volatility spillovers from these markets. See (13). Moreover, a linear combination of certificate, electricity, and equity index price may converge to a stationary process indicating a long-run equilibrium relationship between these variables, as presented in (12).

$$\text{Certificate}_t = C + \text{Electricity}_t + \text{Equity}_t \tag{12}$$

For this to occur, it is necessary to test if the three time series are cointegrated avoiding a spurious regression (Engle and Granger, 1987; Johansen, 1991). Assuming that cointegration is confirmed, it is possible to use the lagged residuals from the regression of (12) as an error correction term in the mean equation of the model. As such, changes in the return of the certificate price are explained by changes in the independent variables and adjustments towards a long-term equilibrium as indicated in

$$\begin{aligned} r_t &= \rho r_{t-1} + \lambda \Delta eq_{t-1} + \upsilon \Delta el_{t-1} + \gamma EC_{t-1} + \varepsilon_t \\ \varepsilon_t &\sim S_t e_t \\ s_j^2 &= \omega + \sum \phi_i D_i + \alpha \varepsilon_{t-1}^2 + \beta s_{t-1}^2 + \psi \sigma_{eq_{t-1}}^2 + \zeta \sigma_{el_{t-1}}^2 \end{aligned} \tag{13}$$

where Δel and Δeq are the first difference of electricity and equity index price, respectively, and EC_t is the error correction term corresponding to the residuals obtained from an Ordinary Least Squares (OLS) regression of (12). $\sigma_{el_t}^2$ and $\sigma_{eq_t}^2$ indicate the variance of electricity and equity index price measured as squared price changes; they are introduced in the variance equation to control for volatility spillovers (Oberndorfer, 2009).

Finally, after estimating the model with different specifications we conclude discussing the impact of regulatory changes and uncertainty on the volatility of certificate price.

5. Empirical analysis

We use the full sample data[1] to estimate three initial models. We start estimating the mean equation of (1) using an OLS method, then we estimate the coefficients of the GARCH model presented in (1), and finally, we estimate a GARCH model with a seasonal dummy variable (κ) added to the mean equation which takes the value of zero during the first semester of the year and one otherwise. The last model estimation aims to verify if there is a pattern of seasonality in the certificate price return. In fact, observing Figs. 1 and 2 it seems that, from 2009 onwards, the certificate price tends to decrease in the first part of the year to increase afterwards. The results of the three models estimation are resumed in Table 3.

The ARCH Lagrange Multiplier test (Engle, 1982) evidences the presence of ARCH effects in the OLS model, indicating that the GARCH model is more appropriate. Instead, the Breusch–Godfrey serial correlation Lagrange multiplier test finds no presence of serial correlation in the residuals of the OLS model. The coefficient of the seasonal dummy indicates that the certificate price return tends to be higher during the second semester of the year; however, this effect is not statistically significant to be considered in our analysis[2].

5.1. Structural breaks in the unconditional variance

We apply the ICSS algorithm to the residuals of the GARCH model estimate (1), searching for breaks in the unconditional variance of the certificate price return. The ICSS indicates two structural breaks corresponding to the weeks going from 8 to 15 March, 2010 and from 5 to 12 September, 2011. For both breaks the *AIT* statistic is statistically significant at a 5% level. The first break coincides with the week in which the government presented the bill aiming to extend the life of the certificate system and to increase the quota requirement. Very importantly, the same week the government presented an assessment indicating its interest in creating a joint market with Norway. The second break, instead, does not coincide with any regulatory change, and falls in the period between June 2011, when Sweden and Norway signed an agreement for a joint market, and November 2011, when the Swedish parliament approved the corresponding bill.

We estimate the GARCH model adding two dummy variables (D_2 and D_6) in the variance equation to take into account for these breaks, as presented in (10). Estimated results are presented in Table 4 (Model 1). The coefficients of the two dummies are both statistically significant and indicate that volatility increased after the first structural break and later decreased in correspondence of the second break. Interestingly, the Wald test cannot reject the null hypothesis of the two dummies coefficients being equal in absolute terms. This suggests that the two breaks enclose a period

[1] At a first glance, there is evidence of an additive outlier corresponding to the first week of April 2008, when the certificate price rose about 12% due to the reduction in certificates surplus (Swedish Energy Agency, 2008). The methodology proposed by Doornik and Ooms (2005) confirms the presence of an additive level outlier (ALO) coinciding with this observation. We correct the raw data prior to model estimation accounting for the ALO as indicated by Doornik and Ooms (2005).

[2] The coefficient remains statistically insignificant also reducing the sample to the period January 1st, 2009–March 25th, 2013.

of higher variability, after which the volatility returned to its previous levels, as represented in Fig. 5. Also, we estimate the model using different dummies specifications to better investigate the role of regulatory changes and uncertainty on price volatility.

Initially, we estimate the model with the first dummy corresponding to other regulatory events related to the Government bill adjusting the renewable quota (Table 4; Models 2, and 3):

- D_1 – The Swedish parliament increases the RES target on the 16th of June 2009;
- D_3 – The Swedish parliament approves the adjusted quota proposed by the government on the 1st of July 2010.

Then, we estimate the model changing the second dummy to reflect other events related with the creation of a joint Swedish/Norwegian market (Table 4; Models 4, 5, 6, and 7):

- D_4 – The Swedish and Norwegian governments sign a protocol to create a common market on the 8th of December 2010;
- D_5 – Two governments sign an agreement for the joint market on the 29th of June 2011;
- D_7 – The Swedish government approves the new market regulation on the 30th of November 2011;
- D_8 – The new market becomes effective on the 1st of January 2012.

An analysis of Table 4 evidences that the coefficients ρ, ω, and α are always statistically significant and their value oscillates between 0.33145 and 0.33753, 0.00011 and 0.00015, 0.18713 and 0.24821, respectively. β varies between 0.33933 and 0.48096, but is not significantly different from zero for model 7. In all the model specification the coefficient of the first dummy indicates an increase in the unconditional variance of the certificate price,

Table 3
OLS and GARCH (1,1) model estimates without dummy variables. Standard errors in parenthesis.

	OLS r_t	GARCH r_t	GARCH r_t
ρ	0.2444***	0.3147***	0.3082***
	(0.0648)	(0.0639)	(0.0631)
κ	–	–	0.0015
			(0.0016)
ω	–	0.0001*	0.0001*
		(0.0001)	(0.0001)
α	–	0.2169***	0.2063***
		(0.0616)	(0.0617)
β	–	0.5635***	0.5835***
		(0.1420)	(0.1364)
ARCH LM (Chi-sq.)	27.66***	9.29	9.69
B-G Serial Correlation LM (Chi-sq.)	13.60	–	–
AIC	−4.6374	−4.6869	−4.6835

*Shows significance at 10% level.
**Shows significance at 5% level.
***Shows significance at 1% level.

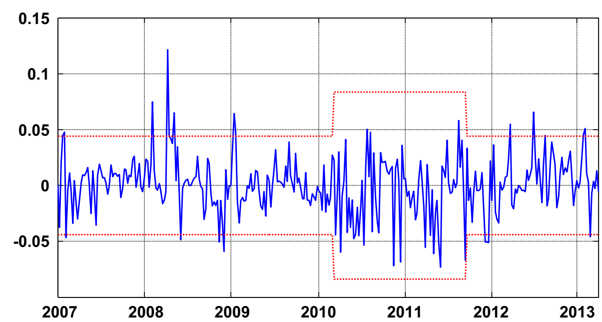

Fig. 5. Certificate price returns and three standard deviations bands for the volatility regimes defined by the structural breaks identified by the ICSS algorithm.

Table 4
GARCH (1,1) estimates with different dummy variables. Bollerslev-Wooldridge (1992) heteroskedasticity robust standard errors in parenthesis.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ρ	0.33473***	0.33145***	0.33150***	0.33753***	0.33552***	0.33423***	0.33559***
	(0.0646)	(0.0642)	(0.0621)	(0.0630)	(0.0652)	(0.0645)	(0.0649)
ω	0.00014**	0.00012*	0.00012**	0.00011*	0.00015**	0.00014**	0.00015**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
α	0.23032***	0.24283***	0.24821***	0.18713***	0.22380***	0.21301***	0.2092***
	(0.0787)	(0.0754)	(0.0732)	(0.07212)	(0.0788)	(0.0752)	(0.0781)
β	0.36541*	0.43737**	0.47089***	0.48096**	0.33933*	0.37934*	0.3455
	(0.2036)	(0.1810)	(0.1636)	(0.2114)	(0.2017)	(0.2113)	(0.2212)
D_1 (Jun-09)		0.00016*					
		(0.0001)					
D_2 (Mar-10)	0.00038**			0.00040*	0.00043**	0.00034*	0.00037**
	(0.0002)			(0.0002)	(0.0002)	(0.0002)	(0.0002)
D_3 (Jul-10)			0.00026				
			(0.0002)				
D_4 (Dec-10)				−0.00031			
				(0.0002)			
D_5 (Jun-11)					−0.00034*		
					(0.0002)		
D_6 (Sep-11)	−0.00032*	−0.00012	−0.00023				
	(0.0002)	(0.0001)	(0.0002)				
D_7 (Nov-11)						−0.00028*	
						(0.0002)	
D_8 (Jan-12)							−0.00032*
							(0.0002)
Wald-Test (Chi-sq.)	0.7751	0.3962	0.2983	1.6449	1.2367	0.6788	0.4164
AIC	−4.7492	−4.7039	−4.7234	−4.7414	−4.7452	−4.7440	−4.7489

* Shows significance at 10% level.
** Shows significance at 5% level.
*** Shows significance at 1% level.

Table 5
Taylor/Schwert GARCH (1,1) estimates with different dummy variables. Bollerslev-Wooldridge (1992) heteroskedasticity robust standard errors in parenthesis.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ρ	**0.35150*****	**0.35158*****	**0.34142*****	**0.34899*****	**0.35062*****	**0.35060*****	**0.34877*****
	(0.0633)	**(0.0629)**	**(0.0604)**	**(0.0626)**	**(0.0640)**	**(0.0633)**	**(0.0632)**
ω	**0.00782*****	**0.00633*****	**0.00654*****	**0.00649***	**0.00847*****	**0.00803*****	**0.00832*****
	(0.0036)	**(0.0030)**	**(0.0031)**	**(0.0036)**	**(0.0038)**	**(0.0038)**	**(0.0039)**
α	**0.21589*****	**0.22515*****	**0.22376*****	**0.17714*****	**0.20394*****	**0.20602*****	**0.19645*****
	(0.0663)	**(0.06390)**	**(0.0624)**	**(0.0661)**	**(0.0672)**	**(0.0659)**	**(0.0675)**
β	**0.40817***	**0.49378*****	**0.50341*****	**0.50750*****	**0.38003***	**0.40323***	**0.39336***
	(0.2096)	**(0.1733)**	**(0.1777)**	**(0.2192)**	**(0.2188)**	**(0.2230)**	**(0.2315)**
D_1 **(Jun-09)**		**0.00349***					
		(0.0019)					
D_2 **(Mar-10)**	**0.00711*****			**0.00717***	**0.00780*****	**0.00667***	**0.00686***
	(0.0035)			**(0.0042)**	**(0.0039)**	**(0.0035)**	**(0.0035)**
D_3 **(Jul-10)**			**0.00503***				
			(0.0030)				
D_4 **(Dec-10)**				**−0.00474**			
				(0.0032)			
D_5 **(Jun-11)**					**−0.00557***		
					(0.0031)		
D_6 **(Sep-11)**	**−0.00571***	**−0.0025**	**−0.00446***				
	(0.0030)	**(0.0016)**	**(0.0026)**				
D_7 **(Nov-11)**						**−0.00533***	
						(0.0023)	
D_8 **(Jan-12)**							**−0.00585***
							(0.0031)
Wald-Test (Chi-sq.)	**0.7887**	**0.4660**	**0.1894**	**1.9807**	**1.3083**	**0.6328**	**0.3430**
AIC	**−4.7547**	**−4.7122**	**−4.7259**	**−4.7425**	**−4.7483**	**−4.750**	**−4.7551**

* Shows significance at the 10% level.
** Shows significance at the 5% level.
*** Shows significance at the 1% level.

and the second dummy a reduction. The two dummies are both statistically significant for models 1, 5, 6, and 7. Only one coefficient is statistically different from zero in models 2 and 4, while for model 3 they are both non-significant. The Wald test cannot reject for any of the seven models the null hypothesis that the coefficients of the two dummies are equals in absolute terms. Also, the Akaike Information Criterion (AIC) indicates that model one should be preferred (Akaike, 1974).

We also estimate a Taylor/Schwert GARCH model to verify if by modeling the conditional standard deviation instead of the conditional variance our results remain unchanged. Table 5 indicates that the estimated coefficients are very similar, although a little more significant for the Taylor/Schwert model. Importantly, the coefficients of the dummy variables indicate that the conditional standard deviation increases and successively decreases, confirming the results of the GARCH model. Again, the Wald test cannot reject for any of the seven models the null hypothesis. Overall, these results confirm those previously obtained with a GARCH model.

Despite the fact that no exogenous factor is considered in this first analysis (see next session), results indicate that the certificate market went through a regime of higher volatility between 2010 and 2011, hampered by regulatory intervention. In particular, regulatory changes could have caused a more volatile market for two reasons. First of all, as indicated by Amundsen and Nese (2009), the introduction of a higher quota level has an indeterminate impact on the demand for certificates. In fact, an increase in the quota requirement does not necessarily lead to an increase in the production of renewable electricity, but only guarantees an increase in the share of RES over total electricity consumption and reduced generation from fossil fuels. Furthermore, the assessment indicating the possible creation of a joint market added some ambivalence regarding future quota levels for Norway, affecting the expectations of future certificate demand. In both cases, regulatory changes generated uncertainty about future certificate prices affecting the ability of market agents to forecast correctly the future. The fact that volatility returned to pre-2010 levels afterwards, indicates that instability was caused by temporary incertitude. Indeed, after uncertainty dissolved, the certificate market restored its previous price variability. Notably, while the end of the discussion regarding the joint market led to a decline in certificate price volatility, this has remained unaffected by the bigger size of the market compared to pre-2010 levels.

Scandinavian policy makers were expecting a bigger market to lead towards more stable and lower prices due to resources diversification and improved liquidity. However, our analysis indicates that price volatility has not benefitted from the bigger market, yet. This can be explained as the new market is still in an initial phase, since obliged entities had to surrender certificates for the first time since its creation in March 2013. Moreover, the initial quota obligation for Norway was quite low, 3% compared to the 17.9% of Sweden. Thus, it is possible that the size effect will become more important in future years with rising quota and increasing market maturity. However, it should also be considered the role of market power as a stabilizing factor for certificate prices (Gross et al., 2010). Indeed, increased competition will lead to lower prices, nonetheless, policy makers should be aware that competition could also offset some benefits deriving from a bigger market in terms of price stability.

5.2. Controlling for the influence of exogenous variables

In this section we continue investigating certificate price volatility by studying the role of exogenous factors such as electricity, and equity markets. By considering the impact of exogenous variables on the certificate price variance, we can verify if the regime of higher volatility was due to regulatory changes, or was caused by volatility spillovers from these markets.

We introduce electricity and equity index price as explanatory variables in the GARCH model[3]. As indicated in (13), we add the

[3] Multicollinearity is not a cause of concern since the correlation between equity index and electricity price returns is 0.077561 while the Variance Inflation Factor is 1.0001.

squared electricity and equity index price changes to the variance equation (Oberndorfer, 2009; Chevallier et al., 2011). Also, we include the return of electricity and equity index price in the mean equation of the model and test if the three time series are cointegrated following a long-term relationship.

In order to do so, we perform the Johansen (1991) test for cointegration on certificate, electricity, and equity index prices. The null hypothesis of the test is that there are r cointegrating relationships against the alternative that the cointegrating relationships are more than r. Both test statistics reject the null hypothesis of no cointegration indicating that one cointegrating relationship exists as indicated in Table 6.

Table 6
Test statistics of the Johansen (1991) test for cointegration. The test is implemented with a constant and no linear trend in the cointegrating relationship. The number of lags is chosen based on the Schwarz (1978) information criterion.

Null hypothesis	$r=0$	$r=1$	$r=2$
Maximum eigenvalue	23.8465**	6.9195	9.1645
Trace statistic	33.1623*	9.3158	2.3963

***Shows significance at 10% level.
**Shows significance at 5% level.
***Shows significance at 1% level.

Thus, we regress the certificate price on the electricity and equity index prices using the OLS method as indicated in (12). Then, the model in (13) is estimated by regressing certificate price changes on lagged changes of the explanatory variables and on the lagged residuals obtained from the regression of (12). The latter represents the error correction term (EC_{t-1}) of the mean Eq. (13), which captures the level of disequilibrium from the long-run cointegrating relationship. Estimation results of (13) are resumed in Table 7.

The autoregressive coefficient of the certificate price return remains statistically significant and its value only slightly decreases compared to previous estimations. Interestingly, neither the electricity nor the equity index price returns influence the certificate price. Instead, it seems that the variance of the certificate price is positively affected by the variance of the equity market, with the coefficient of this variable statistically significant in five over seven model specifications. On the other hand, no volatility spillovers are found from the electricity to the certificate market. The ARCH (α) and GARCH (β) coefficients are slightly different from previous model estimates. Introducing explanatory volatility variables has led to lower ARCH coefficient estimates, meanwhile, the GARCH coefficient has increased, indicating a process with higher autocorrelation in variance and lower impact of new information on price volatility.

Remarkably, the coefficients of the two dummies are both statistically different from zero in five of seven model

Table 7
Cointegrated-GARCH (1,1) model estimates with dummy and exogenous variables. Bollerslev-Wooldridge (1992) heteroskedasticity robust standard errors in parenthesis. The number of lags are chosen based on the Akaike (1974) information criterion.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ρ	0.30337***	0.31779***	0.31254***	0.31220***	0.30342***	0.30229***	0.30414***
	(0.0608)	(0.0648)	(0.0622)	(0.0628)	(0.0615)	(0.0558)	(0.0559)
λ	0.08465	0.06090	0.05092	0.05221	0.08158	0.07512	0.07564
	(0.0565)	(0.0574)	(0.0584)	(0.0582)	(0.0566)	(0.0514)	(0.0518)
υ	0.00120	0.00154	0.00156	0.00161	0.00150	−0.00106	−0.00110
	(0.0087)	(0.0035)	(0.0034)	(0.0035)	(0.0086)	(0.0093)	(0.0094)
γ	−0.00001	−0.00000	−0.00001	−0.00001	−0.00001	−0.00001	−0.00001
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ω	0.00005*	0.00005**	0.00007***	0.00007***	0.00006*	0.00002*	0.00003
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
α	0.10715**	0.20657***	0.21931***	0.16204**	0.12728**	0.00000	0.00000
	(0.0505)	(0.0713)	(0.0719)	(0.0680)	(0.0536)	(0.0000)	(0.0000)
β	0.57962***	0.53660***	0.54400***	0.55374***	0.51771***	0.79797***	0.77178***
	(0.1541)	(0.0923)	(0.0887)	(0.0842)	(0.1526)	(0.0742)	(0.0966)
ψ	0.06494*	0.0636*	0.05401	0.06198*	0.08333*	0.03867*	0.04138
	(0.0389)	(0.0364)	(0.0337)	(0.0353)	(0.0442)	(0.0232)	(0.0259)
ζ	0.0001	−0.00054	−0.00055	−0.00054	0.00013	0.00052	0.00054
	(0.0004)	(0.0005)	(0.0005)	(0.0005)	(0.0004)	(0.0005)	(0.0005)
D_1 (Jun-09)		0.00015**					
		(0.0000)					
D_2 (Mar-10)	0.00028*			0.00038**	0.00033**	0.00017**	0.00018**
	(0.0001)			(0.0002)	(0.0001)	(0.0001)	(0.0001)
D_3 (Jul-10)			0.00022*				
			(0.0001)				
D_4 (Dec-10)				−0.00030*			
				(0.0002)			
D_5 (Jun-11)					−0.00028**		
					(0.0001)		
D_6 (Sep-11)	−0.00022*	−0.00009	−0.00017				
	(0.0001)	(0.0001)	(0.0001)				
D_7 (Nov-11)						−0.00014**	
						(0.0001)	
D_8 (Jan-12)							−0.00015**
							(0.0001)
Wald-Test (Chi-sq.)	1.1662	8.4870***	4.5124**	18.284***	1.1025	2.7676*	2.5404
AIC	−4.7508	−4.7167	−4.7276	−4.7576	−4.7559	−4.7543	−4.7560

* Shows significance at 10% level.
** Shows significance at 5% level.
*** Shows significance at 1% level.

specifications, even after accounting for exogenous explanatory variables. However, in this case the Wald test rejects the null hypothesis of the two coefficients being equal in absolute terms in four over seven model specifications. These results confirm that regulatory changes caused a stage of higher variability in the certificate market and that the creation of a bigger market with Norway has not led yet to more stable prices as expected by Scandinavian policy makers. Instead, after the creation of the joint mechanism the market might be more volatile than in the past.

6. Conclusions

To our knowledge, this article contributes with the first econometric study of the Swedish certificate market, investigating the role of regulatory changes on the volatility of certificate prices. Particular attention is given to the process that led to the creation of a joint market together with Norway. We present an econometric analysis based on the estimation of a GARCH model using a sample of weekly observation from January 1st, 2007 to March 25th, 2013. GARCH models assume no constant variance allowing for volatility clustering, for this reason are very often used to study financial time series.

Initially, we apply an endogenous structural break test to the residuals of a GARCH model to detect changes in the unconditional variance of the certificate price (Inclan and Tiao, 1994; Sanso et al., 2004). The test find two breaks in the analyzed period corresponding to the weeks going from 8 to 15 March, 2010 and from 5 to 12 September, 2011. We relate these breaks to regulatory changes occurred in the Swedish certificate market. More specifically, the first break corresponds to the government's proposal of adjusting the certificate quota together with the presentation of an assessment aiming to create a joint market with Norway. The second break is related to the end of the political process encompassing the establishment of a common market, happening in the period between when the two governments signed an agreement and when the Swedish parliament finally approved it.

We introduce dummy variables in the variance equation of the GARCH model corresponding to the two breaks, finding that volatility increases around March 2010, remains higher until the second break, and decreases afterwards. Furthermore, we estimate the model using dummy variables corresponding to different events related to these two regulatory changes, obtaining similar results. Notably, in none of the model specifications the Wald test can reject the null hypothesis of the two dummies' coefficients being equals in absolute terms, indicating that the certificate market experimented a phase of higher variability, after which volatility returned to its previous levels.

Including explanatory variables in the variance equation of the GARCH model, such as the variance of the electricity and equity index price, we found some evidence that the volatility in the certificate market is positively affected by the volatility of the equity market. Instead, results reveal no evidence of volatility spillovers from the electricity market. Remarkably, after accounting for exogenous factors, results confirm that regulatory changes generated a regime of higher volatility in the market between 2010 and 2011. In this case, results also indicate that, after this period of uncertainty, the market might remain more volatile than in the past. Thus, our results undermine the expectation of Scandinavian policy makers regarding the possibility of obtaining more stable prices through a bigger market. Of course, increasing market maturity and rising quota may indeed lead to lower price volatility in the future. However, it could also be possible that increased competition has offset the benefits of a wider and more diversified market.

Concluding, these results provide evidence for the negative impact of regulatory changes in certificate markets, indicating that regulatory uncertainty leads to increased volatility, exacerbating price risk and restraining investors. Therefore, policy makers should be very careful in changing the regulatory framework of certificate markets, deeply investigating the impact of their decisions on future certificate prices before to act. Moreover, policy makers should accompany regulation adjustments spreading detailed information regarding the expected long-term impact on certificate prices. In such a way, the regulator can help market agents, especially small players that have no access to detailed analysts' information, to better forecast future prices reducing uncertainty and market volatility. Regarding multinational markets, this analysis highlights how the long political process required for establishing an international market could generate a phase of higher regulatory uncertainty. While it is probably difficult to reduce the duration of such a bureaucratic procedure, the regulator should try to make the transition as smooth as possible, by following an open process, disclosing as much information as possible about the status of the discussion, future quotas, expected starting date of the new market, and all the information that could help better forecasting the evolution of the market.

Future research should investigate if the certificate price decreased after the creation of a Swedish/Norwegian market following policy makers' expectations. Doing so, it would be possible to measure the cost reduction for Sweden to comply with its renewable energy target. The role of market power on certificate price and price volatility is another topic worth further analysis.

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