# Evaluating Emission Trading as a Policy Tool – Evidence from Conditional Jump Models

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## Abstract

This paper, first, empirically investigates European emission allowance (EUA) prices and, second, evaluates emission trading as a policy measure. Applying combined jump GARCH models yields strong evidence of conditional jump behavior. This implies that EUA prices are subject to unexpected movements and that a considerable degree of uncertainty is present. According to the real option literature, uncertainty has adverse effects on investment decisions. Thus, investments in abatement technologies are likely to be postponed due to the peculiar characteristics of emission allowance prices. Furthermore, this price behavior is at odds with the theoretical notion that emission prices equal marginal abatement costs.


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Keywords: emission allowance prices, jumps, GARCH, real options.

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## 1 Introduction

This paper's contribution to the literature is twofold. First, it empirically analyzes European emission certificate prices (EUA), using Chan and Maheu's (2002) auto-regressive jump-intensity (ARJI)-GARCH model. Second, the real options perspective allows to evaluate the empirical results on certificate prices and derive conclusions on emission trading as a policy tool.

Empirically analyzing emission allowance (EUA) prices receives growing attention in the literature. Several papers study the behavior of carbon prices and the development of the European carbon market. Most relevant results for this paper are from Daskalakis et al. (2009) who argue that the EUA future is characterized by jumps. Moreover, Paolella and Taschini (2008) as well as Benz and Trück (2009) find GARCH structure in the carbon price returns. However, jumps and conditional heteroscedasticity has not yet been treated in a single approach as brought forward in this paper. A combined approach is motivated by the particular strong influence of regulatory changes in carbon markets, such as decisions on the absolute supply, the allocation to different sectors or the manner of distribution. This particularity of carbon markets has been emphasized in a few recent papers, such as Yang et al. (2008) and Tuthill (2008). They conclude that regulatory decisions lead to jumps in the price data. In order to incorporate such discrete events, the empirical model allows for jumps as well as GARCH effects. Strong evidence of conditional jumps is found, which indicates that a considerable degree of uncertainty is present in the carbon market.

Given these results, policy implications are derived by assessing the effect of uncertainty from the real option perspective. This approach establishes an inverse relationship between uncertainty and investment, especially in the case of irreversible and industry-specific investments. According to Dixit and Pindyck (1994) a firm chooses to delay the expenditure with the prospect of gaining information on the profitability of a project. This insight can be applied to the specific situation of firms within the European Emission Trading Scheme (ETS). Here, firms face a fundamental decision - either they acquire sufficient certificates in the market or they reduce the carbon emissions they generate by investing in abatement technologies. Cleaner and more efficient production process save costs of future certificates and energy, but also represent irreversible expenditures. As the peculiar behavior of certificate prices introduces additional uncertainty, the real option literature predicts a delay of firm's abatement investment.

## 2 Method

Chan and Maheu's (2002) method extends traditional GARCH models by a conditional-jump component. This section briefly outlines this method.[1]

Consider the following model:

$$y_t = \mu + \sum_{i=1}^{l} \phi_i y_{t-i} + \sqrt{h_t} z_t + \sum_{k=1}^{n_t} X_{t,k} \tag{1}$$

with $z_t \sim NID(0,1)$. $h_t$ is assumed to follow a GARCH($p$,$q$) process [Bollerslev, 1986]:

$$h_t = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i} \tag{2}$$

The conditional jump size $X_{t,k}$, given the history of observations $\Phi_{t-1} = \{y_{t-1}, \ldots, y_1\}$, is assumed to be normally distributed with mean $\theta_t$ and variance $\delta_t^2$: $X_{t,k} \sim N(\theta_t, \delta_t^2)$. The number of jumps $n_t$ that arrive between $t-1$ and $t$ follows a Poisson distribution with $\lambda_t > 0$:

$$P(n_t = j | \Phi_{t-i}) = \frac{\lambda_t^j}{j!} e^{-\lambda_t}, \tag{3}$$

where $\lambda_t$ measures the jump-intensity. Two variants of the model are considered here: a constant jump-intensity model with $\lambda_t = \lambda$, $\theta_t = \theta$, and $\delta_t^2 = \delta^2$; and a time-varying jump-intensity model. For the case of the latter, $\lambda_t$ is assumed to follow the auto-regressive process

$$\lambda_t = \lambda_0 + \sum_{i=1}^{r} \rho_i \lambda_{t-i} + \sum_{i=1}^{s} \gamma_i \xi_{t-i}. \tag{4}$$

[1] For a more thorough discussion of the method the reader is referred to Chan and Maheu's (2002) original paper.

This model class and bivariate extensions of which have been successfully applied to stock market returns [Chan and Maheu, 2002], exchange rates [Chan, 2003; Chan, 2004], and copper prices [Chan and Young, 2006]. The following section presents the results obtained from applying this method to emission allowance prices.

## 3 Results

The model is estimated for daily emission allowance spot prices (24/06/2005 - 29/12/2006) as well as 2008 future prices (22/04/2005 - 15/12/2008). Thus, both Phase I and early stage Phase II data is considered. First log-differences of the data is used and a constant as well as two lags of the spot price and one lag for the future price are included.[2] Table 1 provides the estimation results. It is evident that for both price series all jump parameters are highly significant. What is more, Figure 1 vividly illustrates that the Chan and Maheu (2002) method is very well able to capture the emission allowance price's peculiar behavior. Displayed are the price together with the time-varying jump-intensities. It is evident that periods with larger price movements are accompanied by larger jump-intensities. In particular, the severe drop in the prices end of April 2006 is well captured by the model as indicated by the peak in the jump intensity (lower left panel). Prices dropped, when national emission reports confirmed a significant oversupply with certificates of most European installations. The estimates for the EUA future, furthermore, show that the jump behavior is also present in early Phase II stages, epitomized by the two jump intensity peaks January 2008 and October 2008. Possible sources for these sudden price movements that have been discussed in the literature include NAP announcements and relative changes in trading volumes [Sanin and Violante, 2009] as well as energy prices and unanticipated weather events [Alberola et al., 2008]. It is worth noting that the EUA price

[2]Spot price data from the environmental exchange Bluenext is used and available at www.bluenext.eu. Due to larger trading volumes, the data is preferred to spot price data from the EEX in Leipzig. The spot price sample end has been chosen because of the subsequent decrease of the price series to 0, which can hardly be classified as representative price behavior. The future price data is obtained from the European Climate Exchange (www.ecx.eu).

Table 1: Constant and Time-Varying Jump-Intensity Models

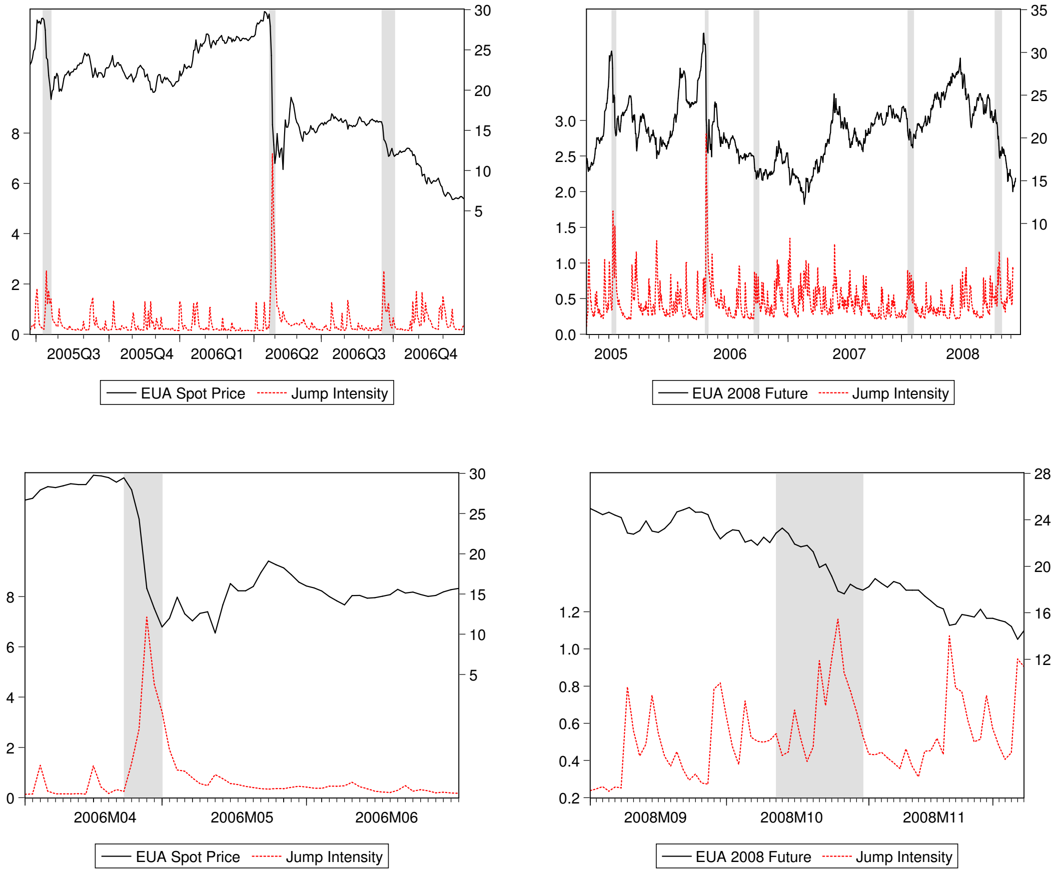
| | Spot price | | Future price | |
|---|---|---|---|---|
| Parameter | Constant | ARJI | Constant | ARJI |
| $\mu$ | 1.6E-03<br>(0.1170) | 0.002<br>(0.0331) | 2.6E-03<br>(0.0028) | 2.8E-03<br>(0.0003) |
| $\phi_1$ | 0.1652<br>(0.0063) | 0.1570<br>(0.0109) | 0.1049<br>(0.0044) | 0.0861<br>(0.0273) |
| $\phi_2$ | -0.0872<br>(0.0960) | -0.1141<br>(0.0340) | - | - |
| $\omega$ | 5.8E-06<br>(0.4106) | 8.9E-07<br>(0.2852) | 1.8E-05<br>(0.0200) | 1.6E-05<br>(0.0229) |
| $\alpha$ | 0.1453<br>(0.0043) | 0.0909<br>(0.0010) | 0.1086<br>(0.0002) | 0.0610<br>(0.0237) |
| $\beta$ | 0.7444<br>(0.0001) | 0.7937<br>(0.0001) | 0.7902<br>(0.0001) | 0.8294<br>(0.0001) |
| $\delta$ | 0.0419<br>(0.0001) | 0.0324<br>(0.0001) | 0.0334<br>(0.0001) | 0.0280<br>(0.0001) |
| $\theta$ | -0.0170<br>(0.0125) | -0.0136<br>(0.0043) | -9.7E-03<br>(0.0468) | -6.7E-03<br>(0.0355) |
| $\lambda$ | 0.2347<br>(0.0011) | 0.1725<br>(0.0139) | 0.2300<br>(0.0118) | 0.1113<br>(0.0968) |
| $\rho$ | - | 0.6115<br>(0.0001) | - | 0.7560<br>(0.0118) |
| $\gamma$ | - | 1.120<br>(0.0007) | - | 0.5138<br>(0.0174) |

Note: p-values in parentheses.

jump behavior is more pronounced than that of Dow Jones returns in Chan and Maheu's (2002) original application. While the height of peaks is similar in both studies, the frequency of peaks as well as the average jump intensity is higher for the EUA prices.

In a nutshell, strong evidence of conditional jumps is found in emission allowance prices, which indicates that the prices are subject to larger unexpected price movements. This, however, suggests that a considerable degree of uncertainty is present in the carbon market. The following section discusses the influence of this apparent uncertainty on the abatement strategy of complying firms.

Figure 1: Emission Allowance Prices and Jump Intensity Intensities




## 4 Discussion

The real option literature is most relevant as it investigates the effect of uncertainty on economic decision making [Dixit and Pindyck, 1994].
Concerning the decision making on the firm level, Bernanke (1983) as well as McDonald and Siegel (1986) point out that irreversible investments are more likely to be postponed if uncertainty on future returns arises. Dixit and Pindyck (1994) emphasize that in this situation the option to wait for additional information becomes more attractive. Uncertainty, for example arising from prices [Pindyck, 1981] or from future demand [Pindyck, 1993] makes future profits hard to calculate. Therefore, theory predicts a nega-

tive relationship between the waiting option and an irreversible investment [Mohn and Misund, 2009].[3]

The real options idea has not only been applied to investment decisions, but also plays an important role in environmental and resource economics. Arrow and Fisher (1974), Fisher (2000) and Pindyck (2000) model uncertainty originating from complex environmental interdependencies and discuss implications for policy decisions. As impact and costs of environmental degradation are hard to assess, the timing of environmental policies and related expenditures becomes more difficult. More recently Dangl and Wirl (2007) investigate how optimal intertemporal emission policies are affected by uncertainty about the temperature curve.

Particularly relevant are papers that apply the real option view to investment decisions under emission trading schemes. Herbelot (1994) and Isney (2003) both analyze the decision to retrofit a power plant under the Clean Air Act in the US, which bans $SO_2$ emissions. What is more, some recent papers employ the real options approach to the ETS. In this specific context, firms face the decision whether to buy sufficient certificates or to reduce the carbon emissions they generate by investing in abatement technologies. Yang et al. (2008) as well as Tuthill (2008) frame a model on abatement decisions under the ETS. They find that the effect of regulatory uncertainty is particularly important within the European framework. By causing jumps in certificate prices, regulatory decisions add disturbance to the carbon market and consequently lead to a delay of investments.

Drawing from this theoretical literature, the evidence of jump behavior pose an additional source of uncertainty in investment decisions, as they make calculation of compliance costs more difficult. Facing this uncertainty, firms become more hesitant about investments and emission-reducing retrofits will be realized later in time.

[3] This conclusion has not been undisputed. Hartman (1972), later extended by Abel (1983) analyze a setting where uncertainty will have an positive or at least ambiguous effect on investment. As a result, this controversy has been investigated in a large number of empirical studies. The results have been surveyed by Carruth (2000). Overall, a negative relationship between uncertainty and investment is confirmed that probably dominates positive effects.

Evidence of jumps is found throughout the estimation period, whereas the intensity of jumps changes substantially over time. As jumps can be found throughout the sample, a considerable degree of uncertainty seems to be inherent in the system. Amongst the influencing factors are fossil fuel prices, weather events and the market power of large firms. Moreover, some extraordinarily high jumps can be ascribed to decisions on provision and allocation of certificates. The event in April 2006 exemplifies how uncertainty is introduced by the regulatory framework. Such influence of regulatory decisions on price behavior has been presumed by Tuthill (2008) as well as Sanin and Violante (2009). Certainly, Phase I was created as test period, introducing regulators as well as firms to the newly installed mechanism. However, the delayed submission of National Allocation Plans for Phase II again created insecurity about the final issuance of all Member States. Further possible sources of disturbance result from the national limits on CDM and JI credits which can be used for compliance within the ETS. The impact of increased auctioning, finally, remains equally unclear. Hence, if regulators do not learn from the Phase I events and improve the system, price uncertainty will remain problematic in the future.
This paper aims to evaluate emission trading and its performance with regard to the reduction of carbon emissions. Evidence is found that investments might be postponed under the ETS. According to Sinn (2008), later abatement of carbon emissions leads to higher atmospheric carbon concentration which accelerates climate change. What is more, the sensitivity of EUA prices to various sources suggests that they do not reflect marginal abatement costs. Therefore, concerns recently expressed by Hintermann (2009) are reinforced. These effects are often neglected when assessing emission trading against other environmental policies.

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