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Energy prices and CO2 emission allowance prices: A quantile regression approach

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Abstract

We use a quantile regression framework to investigate the impact of changes in crude oil prices, natural gas prices, coal prices, and electricity prices on the distribution of the CO_2 *emission allowance prices in the United States. We find that: (i) an increase in the crude oil price generates a substantial drop in the carbon prices when the latter is very high; (ii) changes in the natural gas prices have a negative effect on the carbon prices when they are very low but have a positive effect when they are quite high; (iii) the impact of the changes in the electricity prices on the carbon prices can be positive in the right tail of the distribution; and (iv) the coal prices exert a negative effect on the carbon prices.*

JEL: CO2 allowance price, energy prices, quantile regression.
Keywords: Q47.

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1. Introduction

The literature on the dynamics of the CO_2 allowance prices and volatility has grown rapidly over the last decade. Previous works that mainly use univariate and multivariate linear model have strongly been challenged by the plausibility of nonlinear dynamics for the CO_2 prices (e.g., Daskalakis et al., 2005; Paolella and Taschini, 2008; Seifert et al., 2008; Benz and Trück, 2009). For instance, Daskalakis et al. (2005) show that the spot prices of the CO_2 emission allowances exhibit a random walk volatility behaviour which can be captured by a jump-diffusion model. Paolella and Taschini (2008) find that that a parametric GARCH with a generalized asymmetric *t*-distribution works well for modelling the CO_2 allowance prices. Seifert et al. (2008) argue that the CO_2 prices exhibit a time- and price-dependent volatility structure. Benz and Trück (2009) reproduce the nonlinear dynamics of the CO_2 price returns by means of a Markov-switching model.

There is another strand of the literature that focuses on the price drivers of the CO_2 emission allowance markets. For example, Hintermann (2010) highlights the roles of fuel prices, summer temperature, and precipitation in governing the post-2006 crash CO_2 allowance prices. Kim and Koo (2010) show that the prices of crude oil, coal and natural gas significantly affect the trading of the carbon allowance prices over the short-run.

Other studies have considered the linkages between the spot and futures carbon allowance markets. Chevalier (2010a) emphasizes that the CO_2 futures prices are relevant for the price discovery in the spot emission allowance market. Chevalier (2010b) finds evidence of a positive time-varying risk premium in the CO_2 allowance, which is strictly higher for the post-2012 contracts than for the earlier Phase II contracts. Arouri et al. (2012) stress the importance of asymmetry and nonlinearity in both the return and the volatility of the spot and the futures prices of the carbon emissions allowances.

In this paper, we examine the nonlinear impact of energy prices on the prices of CO_2 emission allowances from the point view of a quantile regression. This framework is especially suited to assess the effects of changes in energy prices on the distribution of carbon prices, that is, during both normal times and periods of extreme variations.

Our results point out that energy prices have generally different impacts on the CO2 prices, depending on whether the latter is at the low or the high quantiles. In particular, we find that an increase in the crude oil prices generates a substantial drop in the CO_2 carbon prices when the latter is very high. This may be due to the fact that higher oil prices can have a strong impact at the high end of the carbon spectrum but without leading to a substitution of coal for oil which is not used in electricity generation. It may also imply that oil prices lead the energy procession and the carbon markets respond to them under extreme conditions.

Additionally, increases in the natural gas prices can have a negative effect on the carbon prices when the latter is very low but a positive effect on those carbon prices when they are quite high. Higher natural gas prices are effective in reducing its consumption and arresting the associated pollution, leading to lower carbon prices when the level of carbon is low or the economy is weak. However, higher natural gas prices at the high carbon spectrum may push power plants to use more coal instead of natural gas, which leads to higher carbon prices particularly when the economy is strong and polluting excessively. These higher prices may also be the result of greater demand for natural gas at the high carbon end. All in all, this implies that natural gas prices do not have the imperial power oil prices have at the high carbon price spectrum.

Concerning the impact of electricity price increases on the carbon prices, the former can have a positive impact at the right tail of the distribution or when the carbon prices are high. This may signal that increases in electricity prices are due to a stronger demand for electricity and/or a lack of substitution of clean energy for the more polluting energy.

Finally, higher coal prices exert a negative effect on the CO_2 emission allowance prices as increases in this fuel prices lead to lower demand for coal and consequent drops in emissions and vice versa. It may also suggest substitution feasibility of natural gas for coal.

2. Material and methods

2.1. Data

Our dataset consists of daily time-series for the prices of the CO_2 emissions allowances, crude oil, natural gas, coal and electricity. The data are sourced from Datastream. The daily sample runs from July 2006 to November 2013, which enables one to investigate the price interactions between the energy and CO_2 emission allowances under both normal and unstable market conditions. The use of quantile regressions also allows us to compare the results under different market spectrums with those of previous studies. .

In our study, the CO_2 emissions allowance price corresponds to the spot price of the European Union CO_2 emissions allowances (denoted by EEXEUAS) obtained from the European Energy Exchange (EEX). We convert these prices from euros to US dollars using the WM/Reuters closing spot rates of the US dollar to euro exchange rate (USEURSP). The crude oil price corresponds to the spot price of the benchmark West Texas Intermediate crude oil. The oil price series is expressed in US dollars per barrel (CRUDOIL). The natural gas price refers to the Henry Hub natural gas spot price which is expressed in US dollars per million British thermal units (NATGHEN). The coal price corresponds to the price of the Coal Intercontinental Exchange (ICE) API2 cost, insurance and freight Amsterdam, Rotterdam and Antwerp NR in US dollars per metric tonne (LMCYSPT). Finally, the electricity price is the South Path 15 Firm Peak electricity price which is also expressed in the US dollars per megawatt hour (WSSPDPF).

2.2. Econometric methodology

To account for the nonlinearity in the relationship between the price of the CO_2 emission allowances and the prices of the four energy sources (crude oil, coal, natural gas, and electricity), we rely on the quantile regression framework to account for the impacts under different market conditions (Koenker and Hallock, 2001). The rationale for selecting this non-linear methodology can be explained by the fact that the distribution of the price of CO_2 emission allowances is best captured by using several quantiles. The quantile regression can reveal information on the asymmetric and non-linear effects of the conditional variables on the dependent variable. It can capture the effect of abrupt changes in energy prices on the sign and intensity of the CO_2 carbon price across different quantiles.

The quantile regression (QR) model can be formulated as follows

$$q_{\boldsymbol{\alpha}}(CO_{2t} \mid I_t) = \boldsymbol{\Phi}_{\boldsymbol{\alpha}} ENERGY_t + e_t, \qquad \boldsymbol{\alpha} \in (0,1). \tag{1}$$

where $q_{\boldsymbol{\alpha}}(CO_{2t} \mid I_t)$ is the conditional quantile of the price of CO_2 emission allowances, $ENERGY_t$ is a specific energy price (i.e. either the crude oil prices, natural gas prices, coal prices, or electricity prices), $\boldsymbol{\Phi}_{\boldsymbol{\alpha}}$ is the slope coefficient measuring the impact of the energy price on the price of CO_2 emission allowances at quantile α, I_t is the information set at time t, and e_t is the error term.

This QR model is less restrictive than the Ordinary Least Squares (OLS) approach, as the slope coefficient $\boldsymbol{\Phi}_{\boldsymbol{\alpha}}$ can vary across quantiles of the dependent variable. In our case, Eq. (1) thus allows for the estimation of the effect of explanatory variables on the time-varying distribution of the price of CO_2 emission allowances.

The parameters of the quantile prediction model are estimated by replacing the conventional quadratic loss function with the so-called 'tick' loss function:

$$L_\alpha(e_{t+1}) = (\alpha - 1\{e_{t+1} < 0\})e_{t+1}, \tag{2}$$

where $e_t = CO_{2t} \hat{q}_{\alpha,t}$ is the forecast error, $\hat{q}_{\alpha,t} = q_\alpha(CO_{2t} \mid \Im_t)$ denotes the conditional quantile forecast computed at time *t*, *α* is a specific quantile of the distribution of the price of CO_2 emission allowances, and $\mathbf{1}\{\cdot\}$ is the indicator function.

The confidence intervals are computed based on the inversion of a rank test. The first-order condition associated with minimizing the expected value of Eq. (2) with respect to the forecast, $\hat{q}_{\alpha,t}$, is the *α*-quantile of the distribution of the price of CO_2 emission allowances. It implies that the optimal forecast is the conditional quantile $\hat{q}_{\alpha,t} = F_\varepsilon^{-1}(\alpha)$, where F_t is the conditional distribution function of the price of CO_2 emission allowances.

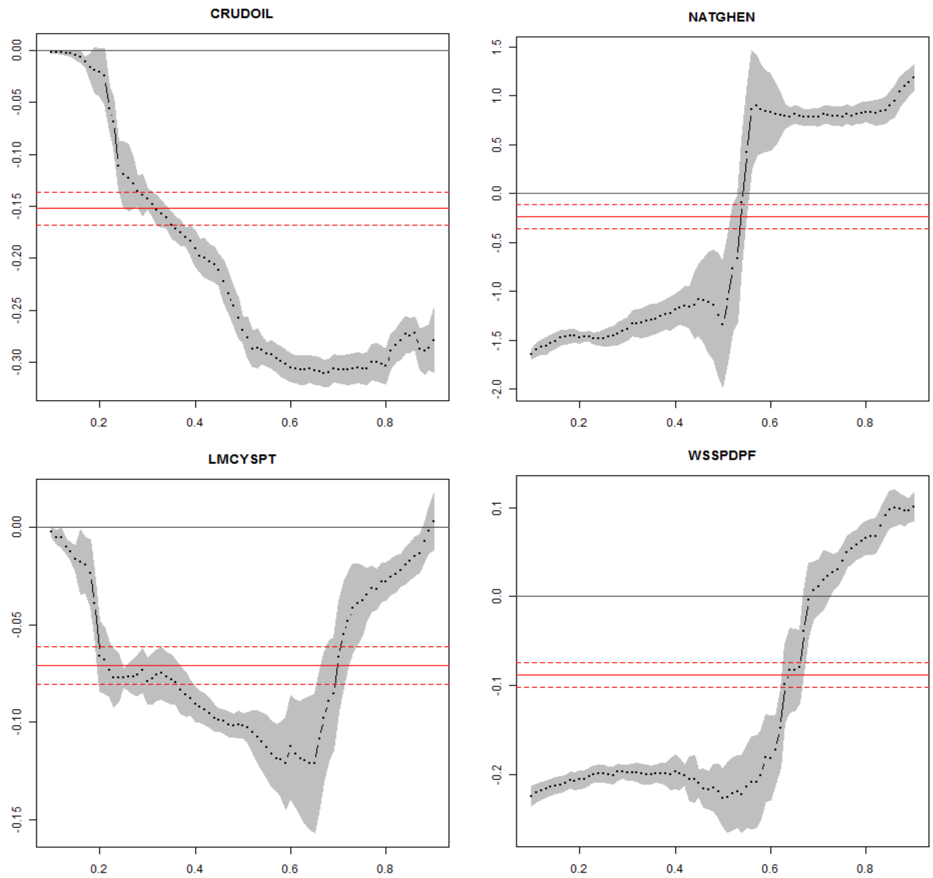
3. Results and discussion

If the effect of the energy prices on the distribution of the price of CO_2 emission allowances is particularly important at specific states of extreme variations, then: (i) a large slope coefficient in Eq. (1) is expected when the price of carbon emissions is sufficiently close to the tails of the distribution; and (ii) a small coefficient should be observed when the price of CO_2 emission allowances is close to the median.

We present the estimated slope coefficients of Eq. (1) for the different energy-CO_2 price pairs in Figure 1. In contrast to the OLS regressions, the quantile regressions provide a richer description of the dynamics of the response of the CO_2 carbon prices to each of the energy prices in the four pairs. The QR results indicate that an increase in energy prices generally leads to a fall in the price of CO_2 emission allowances, which is due to a decline in energy consumption and emissions in response to higher energy prices. Moreover, the sensitivity of the carbon allowance prices to changes in the prices of natural gas and crude oil is particularly relevant, as reflected by the large magnitude of the slope coefficients associated with these energy prices in the quantile regressions.

We find that the negative impact of an increase in the crude oil prices on the price of CO_2 emission allowances is stronger at the right tail of the CO_2 price distribution or when the carbon price is very high. This means that a rise in the crude oil price generates a substantial drop in the carbon prices when the price of CO_2 emission allowances is very high, underscoring the prowess of oil prices in the carbon market.

Figure 1: OLS and quantile regressions for energy-CO_2 price pairs.



Note: The dotted line shows the quantile regression estimates for the quantiles ranging from 0.10 to 0.90; the red solid line represents the OLS coefficient; the two red dashed lines depict the conventional 90 percent confidence intervals for the OLS coefficient; and the shaded grey area plots a 90 percent pointwise confidence band for the quantile regression estimates.

In regard to the effect of an increase in the natural gas prices on the carbon prices, the empirical evidence suggests that this effect is negative at the left tail of the distribution. Higher natural gas prices should generally reduce the consumption of natural gas which in turn reduces the carbon prices and vice versa for lower natural gas prices. This is expected and consistent with the literature (Chevalier, 2012). However, the effect of higher natural gas prices on the carbon price is positive at the right tail of the CO2 price distribution, which may also be due to substitution of coal for natural gas at this spectrum. These results positing that the asymmetric effects happen when the carbon price is at extreme levels are not well documented in the literature. A possible explanation of this extremity may also be attributed to the exceptional low prices of natural gas in the United States compared to other countries and regions, in addition to the high substitution between coal and natural gas in electricity generation. The natural gas prices in Europe are three times the prices in the United States, while in Japan they are four times. This implies that for changes in the natural gas prices to take traction on the carbon prices, the latter should reach extreme positions. This means the natural gas price effect works at the margins, which shows no strong sensitivity for normal or average times in the carbon allowance market.

As for the coal prices, the impact on the carbon prices is typically negative and our findings do not support a major outperformance of the quantile regression framework vis-à-vis the OLS regression in terms of explaining the behavior of the price of the CO_2 emission allowances. This behavior is consistent with the literature (Kim and Koo, 2010).

Finally, the results suggest that, while the effect of changes in the electricity prices on carbon prices is typically negative, it can be positive when the price of CO_2 emission allowances is very high, i.e. at the right tail of the distribution. This result supports the evidence of a positive effect of the natural gas prices on the carbon prices when the latter is very high. On the other hand, some existing studies find a symmetric relationship between those prices using linear models (Kim and Koo, 2010).

Table 1 presents the coefficients associated with the energy prices in using the OLS and the quantile regressions and the Khmaladze (1981) and Koenker and Xiao (2002) tests. The results suggest the relationship between the energy prices and the price of CO_2 emission allowances is negative and statistically significant, which is generally the expected effect as explained earlier. However, the OLS estimates "hide" important variations in the coefficient estimates across the various slices of the distribution of the carbon prices. Indeed, the Khmaladze (1981) and Koenker and Xiao (2002) tests corroborate the outperformance of the quantile regressions (vis-à-vis the OLS regressions) for all four pairs encompassing the energy prices and the carbon price. Moreover, the OLS estimates largely depart from the estimates implied by the median quantiles, being substantially upwardly biased. Thus, the fall in the price of CO_2 emission allowances in response to an increase in a specific energy price is much stronger or overestimated than the one implied by the OLS estimates, after the quantile results are supported by the Khmaladze (1981) and Koenker and Xiao (2002) tests. These discrepancies are larger at the left tale of the distribution. Therefore, the OLS regression is not able to track well periods of extremely low prices of the CO_2 emission allowances.

Table 1: Slope coefficients for the energy-CO_2 price pairs for OLS and quantile regressions.

Quantile	CRUDOIL	NATGHEN	LMCYSPT	WSSPDPF
2.5%	-0.29	-1.48	-0.11	-0.24
25%	-0.28	-1.37	-0.11	-0.23
50%	-0.27	-1.29	-0.10	-0.22
75%	-0.26	-1.20	-0.10	-0.22
97.5%	-0.25	-0.96	-0.09	-0.21
OLS	-0.15***	-0.24***	-0.07***	-0.09***
Khmaladze (1981) and Koenker and Xiao (2002) Test (p-value):	0.00***	0.00***	0.00***	0.00***

Notes: The Khmaladze (1981) and Koenker and Xiao (2002) test computes a joint test that *all* the covariate effects satisfy the null hypothesis of equality of the slope coefficients across quantiles. A rejection favors the quantile method. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Interestingly, we confirm two important results. First, the carbon prices are quite sensitive to variations in the price of natural gas, as reflected in the large (in magnitude) coefficient estimates of the quantile regressions. Second, the magnitude of the responses of the carbon prices to changes in the crude oil, coal and electricity prices is larger (in absolute terms) at the left tail of the distribution, which makes these energy prices particularly relevant at capturing periods of very low carbon prices. This result could be due to tighter regulations or lower economic growth.

4. Conclusions and policy implications

In this article, we assess the relationship between the carbon prices and four energy prices (crude oil, natural gas, coal and electricity) in the United States through using the quantile regression framework. Using daily data for the period 2006-2011, we find increases in the crude oil price leads to a large fall in the carbon allowance prices when they are very high. This result suggests that higher oil prices are effective in reducing energy consumption and arresting its associated fossil pollution when the carbon market is tight. The oil prices also act as the tide that lifts all boats of all energy prices. This finding may justify policies that add taxes to prices of oil and refined products when the carbon market is overheating to encourage the adoption of cleaner sources of energy. The response from the carbon market would be direct and significant to tax-lifted oil prices as they would also be from higher prices due to exporting American oil. Moreover, the empirical findings show that while an increase in the price of natural gas has a negative effect on the carbon prices when these are very low, a rise in the natural gas prices has a positive effect when the prices of carbon are high, which could be due to an associated increase in the natural gas demand. This implies that higher natural gas prices fail to arrest pollution. In this case, adding taxes to natural gas prices or having higher prices due to export does not reduce the carbon prices perhaps because of the high substitutability between natural gas and coal in electricity generation.

Similarly, although electricity prices tend to have a negative effect on the price of CO_2 emission allowances, their impact can be positive at the right tail of the distribution i.e. when the carbon prices are high. This result is similar to that of natural gas prices. Finally, we uncover a negative relationship between coal prices and the price of CO_2 emission allowances which means that higher coal prices reduce its consumption and associated pollution, which leads to lower carbon prices. Higher taxes on coal consumption can be effective in reducing pollution and carbon prices.

From a policy perspective, our findings highlight that energy price variations across quantiles have a significant but differential impacts on the CO_2 allowance prices.. Moreover, the impact is typically asymmetric in the case of the crude oil. This is naturally important, as the carbon price volatility might, in turn, be an impediment to R&D investment in clean energy technologies and renewable energy sources.

Thus, policy measures aimed at reducing the fluctuations in the CO_2 allowance emission prices across the quantiles and the dampening the effects of changes in energy prices can prove fruitful. For instance, by imposing limits on firms' banking emissions allowances during periods when the allowance price is low, and their borrowing allowances when the price is high, the costs of carbon emissions can be reduced substantially. Similarly, safety valves, where the government steps in to supply additional allowances to the market if the allowance price hits the ceiling or a trigger level can help stabilize the price of carbon emissions. Additionally, price collars which restrain price swings by creating a price floor or a price ceiling and operate by providing additional allowances at a predetermined price can mitigate the negative carbon price volatility.

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