Commodity Price Interaction: CO_2 Allowances, Fuel Sources and Electricity

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Abstract This work anlyses the relationship between the returns for carbon, electricity and fossil fuel price (coal, oil and natural gas), focusing on the impacts of emissions trading via a Vector Error Autoregressive Correction Model (VECM) for both German and French markets. Results show that the effect of carbon depends on the energy mix of the country under analysis but that it is not the only factor. Less carbon coercion takes place in the European Energy Exchange (EEX) and innovations in carbon are not strongly reflected in electricity prices. Also, market power affects the correct transfer of prices, thus limiting cost increases.

Keywords CO_2 emission allowance trading · Environmental management · Spot prices · European union · Energy mix impact

1 Introduction

The European Union Emission Trading System (EU ETS) officially began on 1st January 2005 following the 2003/87/EC directive. It is one of the largest multinational emission trading schemes in the world and a major pillar of the EU climate policy created in the ambit of the Kyoto Protocol[1] which aims to cut 1990 levels of CO_2 emissions by 8 %.

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[1] Signatories of the Kyoto Protocol in 1997 decided to reduce greenhouse gases (namely CO_2) by limiting quantified emissions; Under the treaty, industrialized countries agreed to reduce their 1990 levels of greenhouse gas emissions by at least 5 % until 2012.

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The EU ETS sets a ceiling on emissions from the most energy-intensive industrial sectors and introduced the emissions market. Large European CO_2 emitting installations receive permits from their government to emit tonnes of CO_2, and their equivalent is traded on the spot and derivatives markets (mostly options and futures) whenever targets are met at the scheduled time (Mansanet-Bataller et al. 2007).

The energy sector is clearly on the front line of climate change as it is responsible for 60 % of global greenhouse gas emissions and much of the regional and urban air pollution (World Energy Council 2010). Moreover, air quality is a major concern in the urban environment as 50 % of the world's population lives in a city. Emission trading is a market-based scheme aimed at improving the environment and it allows parties to buy or sell both permits for emissions and credits for reductions in the emission of certain pollutants (Dellink et al. 2010). Electricity generation is the main polluting activity in the energy sector and it has been opened up to competition due to the liberalisation of the electricity market in Europe. Electricity is produced from various primary energy sources including nuclear, coal, oil, gas and renewable energies. A country's energy mix is determined by the proportion of the different primary energy sources used in electricity generation. It varies from one European country to another as a result of differences in energy policies as well as geographical and geological features. Electricity prices are therefore determined by the cost of fossil fuels, the impact of environmental policies, and also by climatic factors (Mohammadi 2009).

Carbon allowances are currently traded in electricity exchanges throughout Europe and their price is a result of supply and demand (Benz and Trück 2009). In general, CO_2 production depends on a number of factors such as weather, fuel prices and economic growth (Springer 2003; Mansanet-Bataller et al. 2007; Alberola et al. 2008; Chevallier 2012; Creti et al. 2012).

In this chapter, we intend to extend previous analyses of electricity prices, fuel prices and carbon interactions in at least five ways: (1) our period of analysis is from 2009 to 2012 (Phase II); (2) we broaden previous works to the German and French markets. These countries were selected for the following reasons: the German electricity market is one of the biggest by number of participants and generation capacity, and has strong connections with the rest of the European countries (Madaleno and Pinho 2011a, b); allowances have been traded since 2005 in both markets; the German market is completely open to competition, while the French market is still characterised by monopolistic behaviours; both appear to behave coherently (Silva and Soares 2008; Pinho and Madaleno 2011b); although France and Germany are already geographically close to each other, they formed a regional market in January 2010; (3) We include other fuel prices such as oil due to the energy mix that distinguishes the markets under analysis, and we provide a VECM model with five endogenous variables; (4) we give a clear answer on how the EU ETS has affected the electricity generation sector by addressing countries' heterogeneity (for both short and medium term interactions); (5) finally, we include temperature dummies.

Empirical findings show that in the period under analysis, the European emission allowances market failed to compel electricity producers to reduce their emissions and invest in cleaner technologies whose efficiency depends on the energy mix of the country under analysis. Policies related to the coal industry have therefore a marginal influence on electricity prices.

The remainder of the chapter is organised as follows. Section 2 presents the functioning of the carbon market and its determinants, before showing the data used and its statistical properties in Sect. 3. Section 4 provides the methodology, empirical analysis, results, and policy recommendations, and Sect. 5 concludes.

2 How the Carbon Allowances Market Works and What Affects It

The EU-ETS is the first large scale CO_2 emission trading system in the world. It has been organised in three phases with a pilot phase (Phase I) going from 2005 to 2007,[2] Phase II going from 2008 to 2012 and Phase III of arrangement from 2013 until 2020. The EU ETS is set to expire in 2020 if no other international climate agreement is reached (Creti et al. 2012). Any company wishing to participate in the emission allowances market must open an account in the registry of the country of origin, where allocations are stipulated along with each company's the purchases and sales.

The EU ETS covers more than 11,000 industrial installations in 25 countries; each participating country proposes their National Allocation Plan (NAP) including caps on greenhouse gas emissions for power plants and other sources, which must subsequently be approved by the European Commission. The NAP of each member state determines the total quantity of CO_2 allowances granted per year for each company and for a specific commitment period (each Phase[3]). Allowances are allocated free of charge in the first stage.[4] Thereafter, additional allowances must be purchased directly from the market when required.

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[2] Considered the trial phase when administrative and regulatory bodies were put on-line.

[3] During each of these Phases, allowances delivery is made on a yearly basis and follows a precise calendar: on February 28 of year N, European operators receive their allocation for the commitment year N; March 31 of year N is the deadline for the submission of the verified emissions report during year $N - 1$, from each installation to the European Commission; April 30 of year N is the deadline for the restitution of quotas utilized by operators during year $N - 1$; May 15 of year N corresponds to the deadline of the official publication by the European Commission of verified emissions for all installations covered by the EU ETS during year $N - 1$ (European Commission reports).

[4] This will be limited for Phase III (beginning in 2013), where allowances will not be issued completely free of charge (Friends of the Earth 2010). The allocation of allowances will be made primarily by auction, but until 2020, some allowances will continue to be allocated free of charge to the industrial sector in particular to reduce the costs to facilities in areas considered to be exposed to significant competition, especially from third countries. According to the DG Clima, this decision establishes the rules, including benchmarks for emissions of greenhouse gas emissions, but it is the responsibility of member states to calculate the number of allowances that will be provided free of charge to these areas each year.

The purpose of the EU ETS is primarily to reduce emissions by promoting low carbon technologies and energy efficiency among CO_2 emitting plants and to establish a market price for allowances. European polluters will therefore be aware of the environmental consequences of their polluting activities. As such, installations need to surrender as many allowances during this period as the amount of carbon dioxide emitted during the reference year. The EU ETS is a cap-and-trade scheme; the overall level of emissions is capped up to this limit, and installations short (in excess) of allowances (emissions rights) with respect to their individual allocation level may purchase (sell) allowances on the spot market in order to meet their compliance requirement in the EU ETS (Alberola et al. 2008). Installations that do not meet their target in Phase II must pay a penalty of 100 €/ton of CO_2, up from 40 €/ton of CO_2 in Phase I.

At the start of Phase I, major emitters were allocated an initial amount of permits and were free to trade them on the market. A similar new supply was given every year to the same sources. However, the early environmental benefits were limited because of concerns among member states of over-allocation (Ellerman et al. 2010) and the implementation of banking restrictions between 2007 and 2008; as a result, carbon spot and futures prices of maturity fell to zero levels in December 2007 (Alberola and Chevallier 2009). This first experience also highlighted the need for reliable verified emissions data, harmonised monitoring and reporting rules, as well as concentrated their attention on the first Phase, despite the fact that this was a learning period which revealed the weaknesses of the scheme.

Academics had investigated carbon price patterns in 2005–2007 discussing both their determinants (Alberola et al. 2008; Mansanet-Bataller et al. 2007) and stochastic behavior to forecast trends (Paolella and Taschini 2008; Seifert et al. 2008). Ferkingstad et al. (2011) study the dynamics of price information flow among weekly Nordic and German electricity prices and oil, gas, coal, wind power in Germany and Nordic water reservoir levels but did not take the price of allowances into account. Creti et al. (2012) try to shed light on the determinants of carbon futures prices in Phase II by testing whether energy prices and indicators of economic activity still hold for this phase and evolve toward a stable long-run relationship; they used daily futures contracts from 2005 until 2010 in their cointegration testing. These authors did not include weather variables arguing that the literature thus far only shows that their impact on carbon prices is indirect and captured by sudden shocks in energy demand.

Phase II brought more clarity. The audited figures for each installation were disclosed publicly and installations that had initially received a substantial surplus were subsequently given much less. Supply and demand of allowances was adjusted through exchanges and over-the-counter transactions based on price levels and institutional characteristics of the (Creti et al. 2012).

Economic theory teaches us that carbon price is a marginal cost and that carbon permits have an opportunity cost equal to their market price. Thus, it is to be expected that the price of carbon will be an additional increment to the short-term fuel costs of power generation and must therefore be included in the price of electricity. However, the aggregate effect of carbon prices will depend on the technology mix across the whole of the EU and firms' pricing behaviors. Moreover, electricity prices that reflect the cost of CO_2 are needed to encourage investment in clean generation, demand-side response and the adoption of efficient end-use technologies. The increase of CO_2 in the atmosphere caused by the rampant use of fossil fuels has negative impacts on natural systems and is a main contributor to climate change. Coal and oil should thus be replaced with renewable alternatives which do not emit CO_2. Accordingly, trading allowances for the emission of CO_2 gives value to reducing emissions and has resulted in a market with an asset value worth tens of billions of euros annually.

However, trading CO_2 is different from more traditional commodities. First, whereas producers in this market may hold emission allowances to reduce the costs of adjusting production over time or to avoid stock outs, assets in financial markets can be used for insurance, hedging and speculation. Second, the emissions of sellers are expected to be lower than their allowance, so the unused allowances are bought by those who emit more than their allocated amount. The carbon credit system strives to reduce emissions by encouraging countries to honour their emission quotas and offer incentives to stay below them (Prabhakant and Tiwari 2009; Bhardwaj and Wadadekar 2010). Third, the value of a stock is based on the expected profit of the firm that distributes the shares, while the price of emission allowances is determined by the balance between supply and demand (Benz and Trück 2009). Fourth, while the annual quantity of allocated emission allowances is limited and specified by the EU-Directive for all trading periods, it is the firm that decides whether to issue additional shares and thus fosters the stock's liquidity. Fifth, unlike other markets, emissions trading schemes create a commodity which has one sole producer and supplier, i.e. the government is the only source of allowances and emissions permits. Moreover, there are no apparent production and storage costs. Finally, allowances have a limited validity.

Literature has found evidence that a change in carbon prices is closely linked to the power price (Convery and Redmond 2007). Moreover, German wholesale power prices were found to be closely related to European Union Allowances price change (Zachmann and von Hirschhausen 2008). Also, previous authors analysed CO_2 spot price behaviour (Benz and Trück 2009; Paolella and Taschini 2008; Seifert et al. 2008; Daskalakis et al. 2009) and CO_2 futures markets (Uhrig-Homburg and Wagner 2006, 2008; Wei et al. 2008).

Through Vector Autoregressive (VAR) analysis, long-term and short-term dynamics of electricity, gas and coal prices and the price of carbon permits were studied in the Finnish market (Honkatukia et al. 2007). Similar structural approaches were used to analyse the English electricity market, this time excluding the price of coal and including temperature and dummies as exogenous variables (Bunn and Fezzi 2007).

Previous authors using an autoregressive distributed lag model concluded that other determinants of fossil fuel used in Swedish electricity generation probably diminished the effects of the EU ETS (Widerberg and Wräke 2009). Reasons for the less than 100 % pass-through of CO_2 costs into firm and industry were attributed to demand responses, market structure, and competition from non-fossil fuel generators (Sijm et al. 2006). Among other variables, prices of European Union Allowances (EUA) are also influenced by coal and natural gas prices (Mansanet-Bataller et al. 2007). Moreover, significant interactions are found between European Union Allowances prices and input fuel prices (Bunn and Fezzi 2007). Our results reveal that electricity prices have null short-term responses to CO_2 price shocks, although the response increases over time. This conclusion is the inverse of others taken elsewhere (Fell 2008) using daily data for NordPool for 2005–2008 under a VECM methodology although not using oil prices, but including reservoir levels. For the US market and using VECM, Mohammadi (2009) concludes that there is only a significant long-term relation between electricity and coal, and while the role of oil prices is significant, that of natural gas is statistically weak.

The different results obtained in studies not only reflect distinct approaches but also the fact that the countries surveyed have very diverse energy mixes. The absence of a unanimous response to the problem of the effect of the EU ETS on the price of electricity (Reinaud 2007) is therefore due mainly to the coexistence of various electricity markets in Europe and the heterogeneity of energy mixes. Furthermore, as these studies did not cover any more than the period 2005–2006, on the demand side, carbon prices are impacted by energy prices because they reflect the producing process of the utilities regulated by the EU ETS.[5]

3 Data and Statistical Properties

Electricity prices were obtained from the electricity stock exchanges of Powernext (FR) for France, and European Energy Exchange (EEX) for Germany. We focus on the French and German electricity markets where the major fuel sources are gas, coal and oil (Ferkingstad et al. 2011). The German electricity data collected starts in June 2000 and the French data in November 2001. CO_2 only started to be traded after the liberalisation of electricity markets, namely October 2005 in Germany and April 2005 in France.

Weekly day-ahead (base load price—the day's arithmetic 24 h average) electricity prices (in €/MWh) were obtained by means of the price on the last trading day in the week. Due to data restrictions and the misbehaviour of carbon markets until 2009 our period of analysis is from January 2, 2009 to July 6, 2012. Moreover, Chevallier (2012) identifies three breakpoints in carbon spot series.[6] Our results would not necessarily say much about price information flow between the weekly price levels if we chose the Sunday price, and using weekly average spot prices might have induced additional correlation into the series or differenced price series.

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[5] For more details on the relationship between coal, energy prices and fuel switching behaviour, institutional decisions and weather events between 2007 and 2009 see Chevallier (2012).

[6] These were May 28, 2007; December 30, 2008; and February 11, 2009.

Daily data can avoid additional complications induced by averaging but results obtained when we performed this analysis proved to be less reliable.[7]

The carbon spot price of the respective stock exchange expressed in € per ton was used; in other words, the Bluenext carbon spot European Union Allowances price was used for France, and the EEX-EU CO_2 emissions allowances price was used for the German market. Furthermore, we collected data on exchange rates so that all electricity prices and carbon were in the same denomination as other primary energy fuels used (gas, oil and coal), i.e. we converted all prices to US dollars to control the impact of exchange rates. Monthly exchange rates were collected from the "Bank of Portugal"[8] covering the corresponding sample periods.

For crude oil, we use weekly spot prices of the London Brent Crude Oil Index, one of Europe's benchmarks for crude. Weekly spot prices set on Brent are denominated in US dollars per barrel but transformed into Euros. Brent is a North Sea deposit; as its oil is representative of the crudes produced in this region, it has the best characteristics to match other energy variables traded in Continental Europe (Chevallier 2012). For coal data, we take the Antwerp/Rotterdam/Amsterdam (ARA) coal price which is denominated in US dollars per Gigajoule. Weekly prices on natural gas are those reported in the Zeebrügge Hub where data is denominated in €/MWh. We expect this market to be more important for electricity price formation as it is closer to the German market (Ferkingstad et al. 2011) which is the most liquid gas trading market in Europe. As argued by Chevallier (2012) this market has a major influence on the price that consumers pay for their gas in Europe and therefore constitutes a good proxy. Data descriptive statistics are presented in Table 1. All time series have been log-transformed into returns.

As evidenced by the data, mean returns for all electricity spot markets are positive. The Jarque-Bera statistic indicates that the distribution of returns for all samples has fat tails and sharper peaks (kurtosis) than the normal distribution (kurtosis being higher for natural gas and carbon prices). Skewness, which measures the degree of a distribution's asymmetry, is also very different from zero, and is negative for carbon, natural gas, oil and Powernext electricity returns. Results for skewness and kurtosis are not shown here but are available on request.

Moreover, volatility is high for all markets and there are no significant differences between the average wholesale electricity returns in the two markets. Powernext relies heavily on nuclear power, followed by hydro, and given the results obtained here we are able to confirm the finding that the mix of generation technology has an impact on the standard deviation of market prices (Wolak 1998). Wolak (1998) finds that prices in markets dominated by fossil fuel or thermal technology tend to be much more volatile than prices in markets dominated by hydroelectric capacity. According to the standard deviation obtained, which we use

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[7] Results will be provided upon request.

[8] http://www.bportugal.pt/pt-PT/Estatisticas/PublicacoesEstatisticas/BolEstatistico/Paginas/BoletimEstatistico.aspx.

Table 1 Descriptive statistics for energy and carbon returns

	elect_PN	elect_EEX	Gas	Coal	Oil	CO_2_PN	CO_2_EEX
Mean	0.002	0.002	0.001	0.002	0.006	−0.003	0.033
Median	0.003	0.007	0.007	−0.001	0.005	0.001	0.002
Maximum	0.641	1.070	0.342	0.130	0.157	0.256	6.420
Minimum	−0.860	−1.780	−0.515	−0.116	−0.115	−0.233	−0.217
Std. Dev.	0.197	0.231	0.098	0.034	0.039	0.061	0.477
Jarque-Bera test	86.657	3470.0	183.342	9.976	16.706	64.862	236000.0
Probability	0.001	0.001	0.001	0.015	0.004	0.001	0.001
Observations	184	184	184	184	184	184	184

EEX stands for European Energy Exchange in Germany. PN stands for Powernext in France. The period analysed goes from January 2009 to July 2012 for both EEX and Powernext. The gas, coal and oil series descriptive statistics results are for the same period of electricity and carbon series analysed for both markets. *Std. Dev.* standard deviation; Jarque-Bera test statistic; Probability values are those associated to the Jarque-Bera test; *elect.* electricity return; CO_2 carbon return

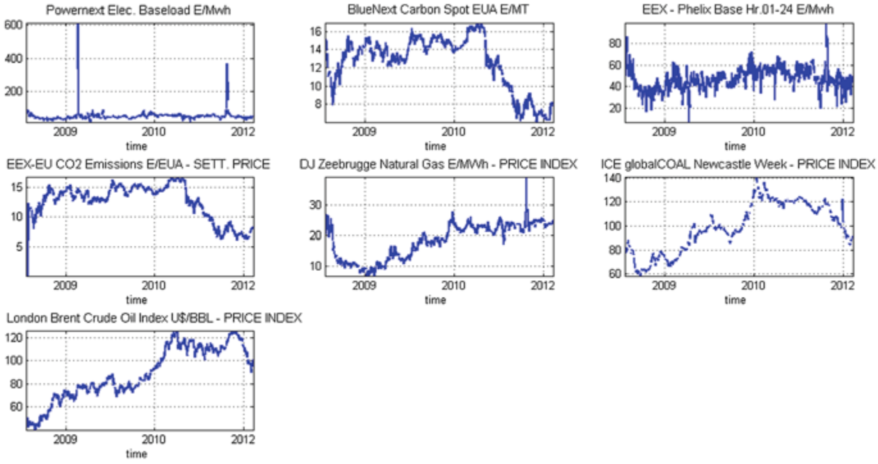

Fig. 1 Weekly price dynamics plots for electricity, gas, coal, carbon and oil

as our volatility proxy, EEX presents higher volatility of both electricity prices and allowances.

Volatility increases costs for emitters and they prefer stable and predictable carbon prices. In the carbon markets, there are generally two types of risk that participants may want to transfer: carbon price volatility and carbon default risk (the risk that offset projects may not achieve some or all of their carbon reductions). Both types of risk would be found in a system with a high proportion of offsets and volatile carbon prices.

Since 2005, electricity prices have been affected by two major changes: an increase in fossil fuel prices and natural gas in particular, and the introduction of CO_2 allowances, itself boosted by increasing gas prices. The two factors have resulted in higher market prices—and costs—for energy intensive users. Figure 1 shows that electricity contract prices have varying volatilities; they are most volatile than of all energy markets, whereas CO_2 volatility is very similar among markets. The price of coal rose sharply in 2010 and only decreased at the end of 2011.

As stated previously, CO_2 emission allowances have a limited validity as they expire after each commitment period. However, the decision to allow banking[9] from the pilot phase (2005–2007) into the first Kyoto commitment period was left to the individual EU member states (whereas Germany decided against allowing it, France permitted it in the initial stage). An intertemporal ban in banking meant all licences became invalid at the end of 2007 and environmental institutions had to

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[9] Banking occurs when the right to emit carbon can be saved for future use, i.e. we can use a 2007 allowance in 2008. On the other hand, borrowing means that current emissions are extended against future abatement, i.e., we can borrow permits from future allocations for use in the current period (using 2008 allowances in 2007). Both banking and borrowing were forbidden between phase I and II.

issue companies with new allowances. Therefore, Phase I spot prices for carbon went down to zero by the end of Phase I due to banking restrictions implemented between 2007 and 2008 (Alberola and Chevallier 2009). This induced an excessive supply of allowances on the market which in turn led to a fall in the carbon price initiating a convergence towards zero in January 2007. Moreover, two structural breaks were also identified in the literature (Alberola et al. 2008) in 2005–2007 and three have since been explored by Chevallier (2012).

The second year in Phase II of the EU ETS, 2009, started with a fall in European Union Allowances prices; this followed the decline that had begun towards the end of 2008 due to the widening of the financial crisis and it stoked fear among market participants of a reoccurrence of the problems at the end of Phase I when allowances were being sold to improve companies' balance sheets (see European Commission reports). As a result we excluded 2008 from our analysis.

Carbon and coal prices seem to follow opposite paths. The price dynamic is consistent with the intuition that when the demand for carbon permits increases, the coal price decreases. They will increase when the relative price of coal decreases because a coal-fired power station is more carbon-intensive than a gas-fired station However, there seems to be a downward trend in both from 2010 onwards with some evident peaks with respect to coal.

The electricity markets under analysis differ in their underlying production structure. The recommendations throughout "green markets" are showing some evolution with respect to hydro and wind. Renewables are still not the main production source for both countries. According to Eurostat data, Germany generated 10 % of its electricity from renewable sources in 2005 and France 10.98 %. In 2008, the figures rose to 14.63 and 14.07 % for Germany and France respectively, followed by another increase for with in 2010 to 16.9 % compared with just 14.45 % for France. This demonstrates the huge effort being made in Germany.

At this stage it is interesting to notice the differences in the energy mix among countries. For example, France has a large nuclear and hydro production (Pinho and Madaleno 2011a). Of the EU-15 countries, France is expected to be a relative winner in the EU emission trading due to its large proportion of nuclear energy[10] (Pinho and Madaleno 2011a). The percentage of nuclear in EEX is also high, and is followed by coal (see Table 2). Germany clearly switched from coal to natural gas and wind, while France is still relying on nuclear. The German EEX market is the largest market in Europe, dominated by coal (47 %), nuclear power (23 %), gas (17 %), hydro and increasing wind power production (Ferkingstad et al. 2011).

Reducing the concentration in the electricity industry was another of the main objectives of the EU Directives: "increasing competition to reduce market power". Table 3 presents the percentage share of the largest generator for the markets under analysis between 1999 and 2010.

As demonstrated by the data, the French market has the highest level of generators concentration but the concentration in both markets was lower in 2010 than

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[10] We were unable to include nuclear, wind or even hydro production due to lack of available data .

Table 2 Percentage of electricity production by fuel source in Germany and France

	Germany		France	
Fuel source/year	1998	2008	1998	2008
Hard coal	27.56	19.56	6.22	4.24
Petroleum	1.15	1.35	2.28	1.02
Natural gas	9.76	11.91	0.97	3.80
Nuclear	29.03	23.30	75.92	76.29
Hydro	3.88	4.23	13.04	11.95
Wind	0.82	6.37	0.00	0.99

Figures are in percentages computed as: (type of fuel used to produce electricity/total gross electricity generated) * 100. Total gross electricity generation (GWh) covers gross electricity generation in all types of power plants. The gross electricity generation at plant level is defined as the electricity measured at the outlet of the main transformers, i.e. it includes the consumption of electricity in the plant auxiliaries and in transformers. The gross electricity generation in power stations burning hard coal (GWh), in power stations burning natural gas (GWh), in nuclear power plants (GWh) and in wind turbines (GWh) are measured as above Gross electricity generation in power stations burning petroleum (GWh) products cover hydrocarbons like motor spirit, gas oil, kerosene, etc. produced in oil refineries or in some rare cases obtained without refining Hydroelectricity covers potential and kinetic energy of water converted into electricity in hydroelectric plants (GWh), also expressed as gross generation. *Data comes from* http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

in 2000. Nevertheless, the high levels of concentration create scope for market power and therefore they influence spot prices, which could induce environmental costs being transferred erroneously to electricity prices (Pinho and Madaleno 2011a).

The correlation matrix between European Union Allowances price markets is also studied for the estimation period. Results are presented in Table 4.

Table 4 shows that European Union Allowances markets have positive pairwise correlations (except between carbon and all the other fuel sources in both markets); although this implies interactions between electricity prices and fuel prices, they are not so strong as initially expected. Higher correlations are observed between gas and electricity, coal and oil, as well as between gas and oil.

Similar to Chevallier (2012) we also considered the broad European temperatures index[11] to be a suitable exogenous variable that drives energy and allowances prices, and therefore included it as a dummy in our model. Weather conditions are expected to affect the price path of carbon by influencing energy demand. In cold winters, more heating is needed and this requires extra power extra power generation. On the other hand, hot summers lead to a greater consumption of air-conditioning, also raising electricity production. However, the fuel used in response to

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[11] See http://www.weatherindices.com/index. Moreover, due to data limitations and lack of availability for the countries considered here we do not consider other potential weather events such as wind.

Table 3 Percentage share of the largest generator of electricity

Market/year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Germany	28.1	34.0	29.0	28.0	32.0	28.4	30.0	31.0	30.0	30.0	26.0	28.4
France	93.8	90.2	90.0	90.0	89.5	90.2	89.1	88.7	88.0	87.3	87.3	86.5

Data comes from http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

Table 4 Correlations among weekly returns for electricity, carbon, gas, coal and oil

Powernext—France						EEX—Germany					
Variable	Elect.	Gas	Coal	Oil	CO_2	Variable	Elect.	Gas	Coal	Oil	CO_2
Elect.	1					Elect	1				
Gas	0.529	1				Gas	0.299	1			
Coal	0.024	0.129	1			Coal	−0.059	0.129	1		
Oil	0.063	0.141	0.276	1		Oil	0.029	0.141	0.276	1	
CO_2	−0.006	−0.073	−0.079	−0.095	1.000	CO_2	−0.023	−0.020	−0.052	−0.039	1

The period analysed for both markets is from January 2009 to July 2012. Figures presented are in absolute terms. Elect. stands for electricity returns, CO_2 for European union allowances (carbon) returns the demand for increased production is not always the lowest CO_2 emitting source; this means more CO_2 allowances are required, which will be reflected in prices. The national business-climate index used was computed by Metnext (the average daily temperature of the regions that compose a country weighted by their population). CDC Climate Research has extended this methodology by creating the European temperatures index (expressed in degrees Celsius), which is equal to the average of the national temperature indices for 18 European countries (including France and Germany), weighted by the weight of each country in the total volume of distributed allowances. For our analysis we define two dummy variables: one to capture the influence of cold temperatures and the other to capture the influence of hot temperatures.[12]

4 Model and Empirical Results

The descriptive statistics provided above indicate that energy series and carbon prices are non-stationary. This implies that any particular price measured over time will not be tied to its historical mean. Moreover, electricity, carbon and fuel prices are not expected to be independent from each other, whereas similar economic forces are expected to influence each market.

In order to address stationarity, the Augmented Dickey-Fuller test (ADF) was used (null hypothesis: non-stationarity of the tested time series), assuming a constant, a constant and a trend and none, for all series (in logs and log first differences) under analysis. The presence of a unit root for all the series after differencing one time is rejected (except for natural gas assuming a constant and a trend). Overall, the series are integrated of order one, I(1), or first-difference stationary, and we conduct the model analysis in logarithmic first differences (returns).[13]

We also tested for cointegration using Engle and Granger (1987) cointegration tests but do not present results in order to save space.[14] Tests performed indicate the existence of 1–2 cointegrating vectors depending on the market under analysis, and the null hypothesis of no cointegration is rejected.

For the empirical estimations, we define $y_t^T = \left(Log_{elec}, Log_{gas}, Log_{coal}, Log_{oil}, Log_{carbon}\right)$, the vector of the log prices of electricity, gas, coal, oil and carbon emission permits. Exogenous variables considered were the lagged values of endogenous variables and the two dummies used for hot and cold extreme temperatures; the Vector Autoregressive Model (VAR) lag order selection indicated

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[12] The dummy that captures the influence of cold temperatures equals one when the temperatures index in a given month is −1.97 °C below decennial seasonal averages and that of the influence of hot temperatures equals one when the temperatures index in a given month is 1.47 °C above decennial seasonal averages.

[13] Results are not provided here but are available on request.

[14] We test for the number of cointegrating vectors using the trace test introduced in Johansen (1992) and the Max-eigenvalue test.

two lags for both markets selected by both LR (sequential modified Likelihood Ratio test statistic) and AIC (Akaike information criteria).[15]

The vector autoregressive (VAR) model (Hamilton 1994) is a standard and useful tool of econometrics and multivariate time series analysis. To explain the model, consider that endogenous variables y_t and exogenous variables x_t are observed random vectors depending on time t = 1, 2, … The main idea of this model is that endogenous variables depend linearly on their p previous values and also the current value of the exogenous variables. For now, we consider a VAR with p-lags (when p is long enough to ensure absence of autocorrelation):

$$y_t = v + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + \delta x_t + \varepsilon_t \tag{4.1}$$

where y_t is a $n \times 1$ vector of variables, v is a $n \times 1$ vector of parameters, $A_1, \ldots, A_p$ are $n \times n$ matrices of parameters, δ is a coefficients matrix of size $n \times d$ and ε_t is a $n \times 1$ vector of disturbances, with mean 0, covariance matrix $\sum$, and i.i.d. is normal over time. In this case, n stands for the number of endogenous variables and d for the number of exogenous variables (x_t).

From the econometric literature, we know that any VAR(p) can be rewritten as a Vector Error Correction Model (VECM) when the stability condition is not satisfied. In fact, all variables must have the same order of integration. If all variables are stationary, I(0), we can easily use the VAR specification. If not, or if the variables are non-stationary, I(k), $k \geq 1$ we can do two things: If the variables are not cointegrated, they must be differenced k times in order to obtain a VAR; but if the variables are cointegrated, we may use a vector error correction model (VECM).

Here we define the VECM of order p as:

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1} + \Phi x_t + \varepsilon_t \quad t \in Z \tag{4.2}$$

where y_t is a $n \times 1$ random vector, $y_t \sim CI(1)$ meaning y_t sequence is a VAR(p) process cointegrated of order 1; $\Pi, \Gamma_1, \ldots, \Gamma_{p-1}$ are $n \times n$ fixed coefficient matrices and ε_t is a $n \times 1$ white noise Gaussian process. In the present setting, we have a VECM with p = 2 for both Powernext and EEX. The Π matrix has a rank $r \leq n$ and $\Pi = \alpha\beta^T$. The $n \times r$, α, matrix is called the loading matrix. The $r \times n$, β, matrix is called the cointegration matrix. The columns of β, β_i are such that $\beta_i^T y_t$ is stable, and are cointegrating vectors. When we find the rank of cointegration for the VECM, y_t, we find the rank of Π, the number of cointegrating vectors β_i (if more than one, otherwise just one vector). Hence, βy_{t-1} can be regarded as an error correction element, with α then being a speed of adjustment vector. Given that we have defined y_t as being the vector of endogenous containing the log prices, Δy_t will be the vector containing log first differences (or else, returns). δ is a coefficients matrix

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[15] Schwartz criteria was also used and given the difference of the selected lag structure and the need to keep the VAR model parsimonious, we ran the χ^2 lag exclusion test.

of size n × d associated with the d × 1 vector x_t that represents the two temperature dummies or exogenous variables. Notice that here n = 5 and d = 2.

Response of $y_{j,t+s}$ to a one-time impulse in $y_{i,t}$ is described by impulse-response functions, with all the other variables held fixed. They can be used to produce the time path of the dependent variables in the VAR to shocks from all the explanatory variables. If the system of equations is stable, any shock should decline to zero, whereas an unstable system would produce an explosive time path. In order to save space we omit the presentation of the VECM estimates.

Figure 2 displays the impulse response functions for all series in the France Powernext, namely the responses of each series to a shock in each series. The horizontal axis represents the up to 9-week responses of all series caused by an impulse (a one-time-only shock) in one of the series (column headers show the impulses and row headers the responses). The responses are normalised so that they can be compared with each other.

Each series response to its own shock shows to be positive, significant and strong in the short term. All series responses to shocks in oil prices seem to be positive, except for electricity in EEX (see Fig. 3), but they do not last across the entire time horizon considered (9 weeks). For Powernext, electricity response to carbon and gas appears to be positive in the short term but negative for coal. With respect to oil shocks, electricity only responds negatively in the 2-week period. Coal responses are generally positive, and natural gas seems to show a positive response to a shock in carbon, while negative for oil between 1 and 2 weeks. Moreover, oil response to coal is found to be sharply decreasing for a 1-week period. Electricity seems to indicate a negative response to carbon prices with a delay of approximately 1 week; the first impact is positive but not strong.

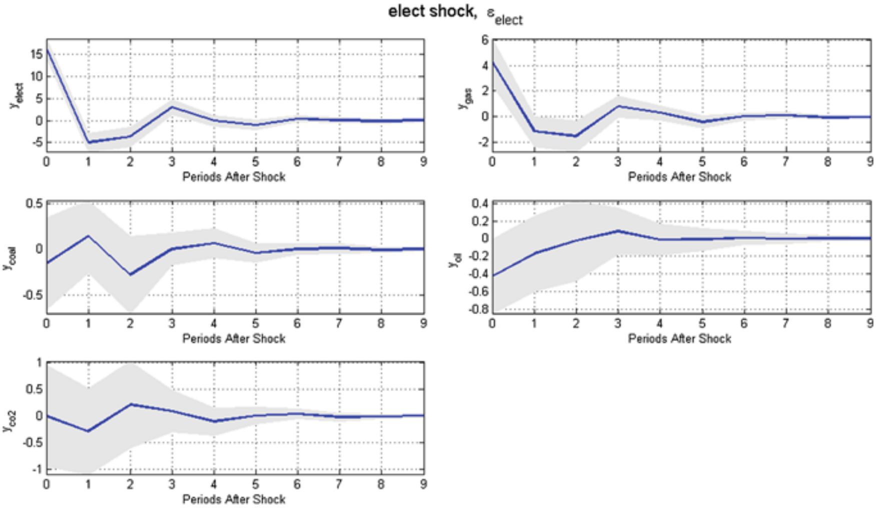

Fig. 2 Impulse response plot for Powernext. Each *column* shows the up to 9-week responses in all series to a one-time-only shock in the series listed in the column header

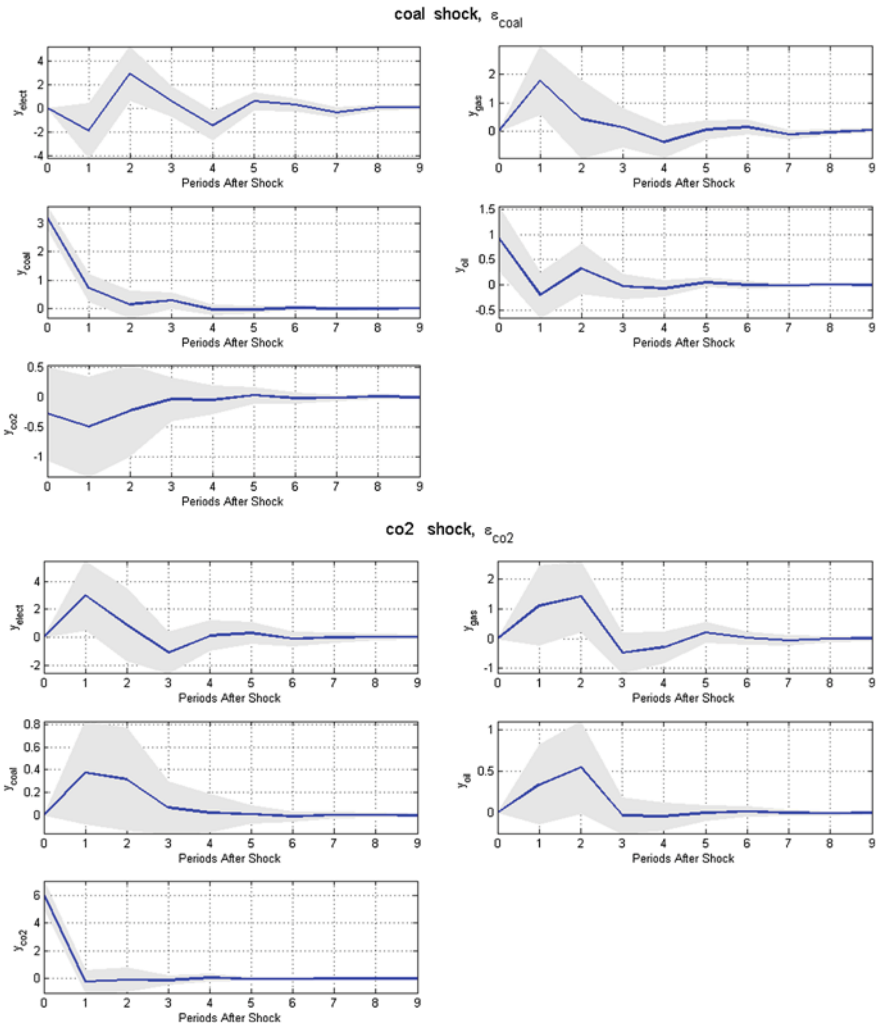

Fig. 2 continued

In addition, CO_2 response to fuel prices proved to be almost negligible in Powernext, although positive for electricity price shocks in EEX. An impact of electricity in natural gas is negative in both markets, but is positive for coal and for oil only after a stable period of 2 weeks. Natural gas seems to react positively in the short term, turning out to decrease after that; oil response to natural gas is negative and persistent until 2 weeks. The response of coal to natural gas disappears after 3 weeks, but coal reacts negatively to oil price shocks. In fact, oil shows the strongest response of all the relevant fuels to CO_2 prices in the short term even though it remains minimal over time. It was observed that whereas electricity prices

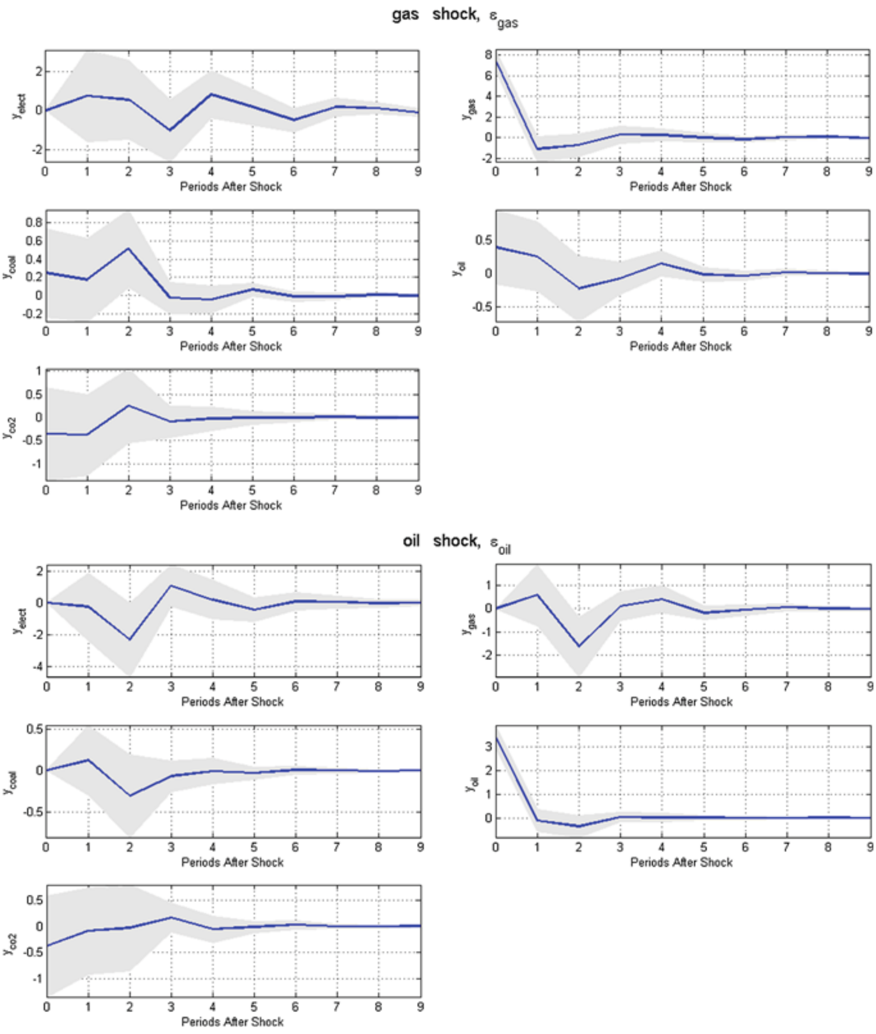

Fig. 2 continued

appear to react negatively after a shock in EEX, they react positively in Powernext, and after compensation in the following periods the response to CO_2 weakens. Moreover, natural gas seems not to respond significantly to European Union Allowances shocks.

Both carbon and gas shocks on electricity prices seem to produce a similar effect in the first week but the gas price shock is completely absorbed after a 3-week period, whether or not the shock in carbon price is persistent and unstable until 4-week, implying a significant marginal effect. This can be explained by the fact that the gas market is relatively mature.

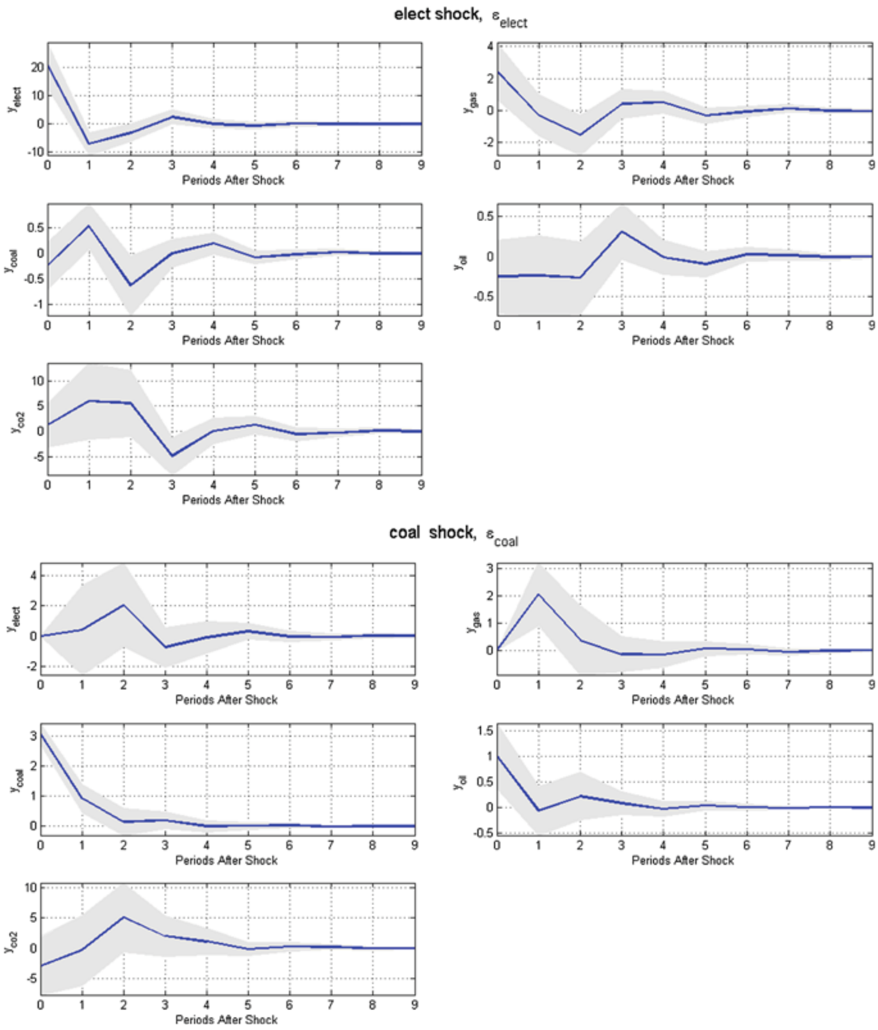

Fig. 3 Impulse response plot for EEX. Each *column* shows the up to 9-week responses in all series to a one-time-only shock in the series listed in the column header

In the German case, gas prices do not seem to be significantly affected by a shock in carbon prices and yet a gas price shock seems to affect both electricity and carbon prices positively. A possible reason is that in the EEX a significant quantity of electricity (around 11.9 %) is produced by gas-fired power stations (see Table 2) and the main initiative, in order to fulfil the Kyoto target, has been to switch from coal to gas, which occurred when we compare the values from 1998 to 2008. Switching becomes more expensive if gas prices are high, and this is reflected in higher carbon prices.

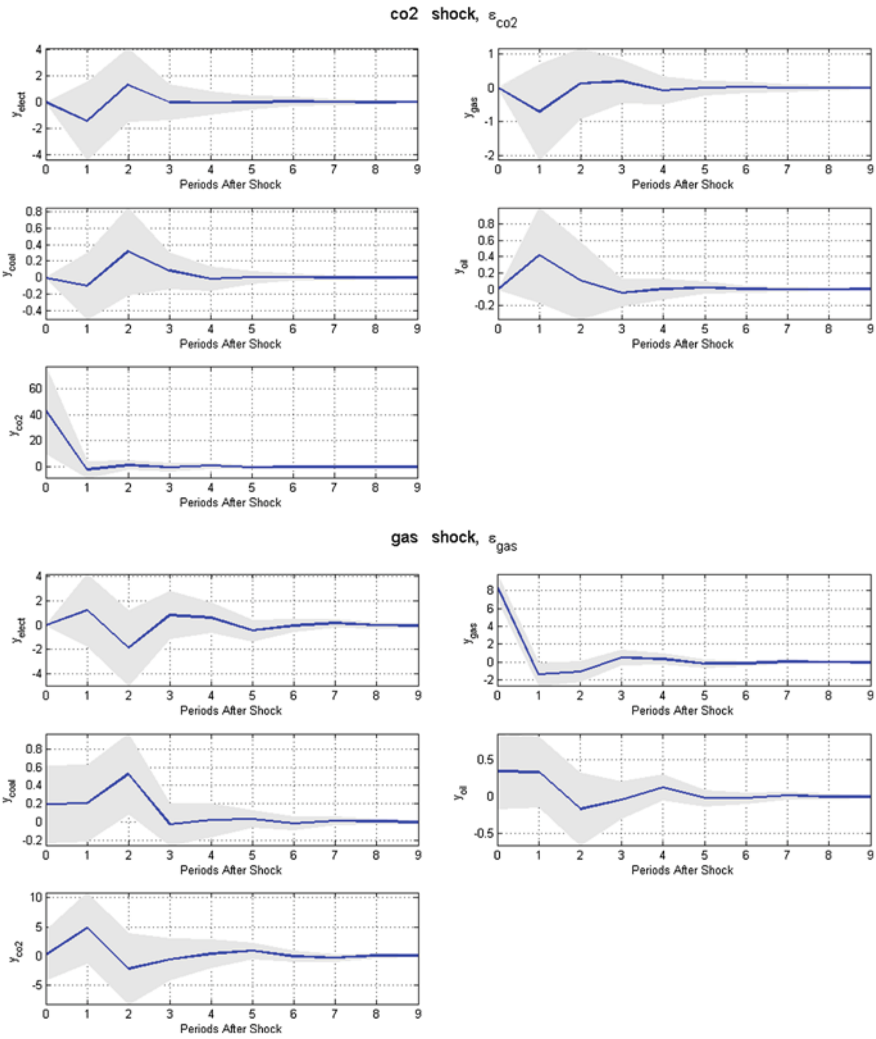

Fig. 3 continued

Despite using impulse response functions, variance decomposition (VD) is useful for examining the effects of shocks on the dependent variables. It determines how much of the forecast error variance for any variable in a system is explained by innovations to each explanatory variable over a series of time horizons. The result will depend on the order in which the equations are estimated in the model and here the selected order was: electricity, natural gas, coal, oil and EU ETS carbon.

Variance decomposition results are provided in Figs. 4 and 5, and Tables 5 and 6, for EEX and Powernext, respectively. Coefficients of the VD can be interpreted as the price of elasticity; this implies for example that a 1 % gas price rise would, in

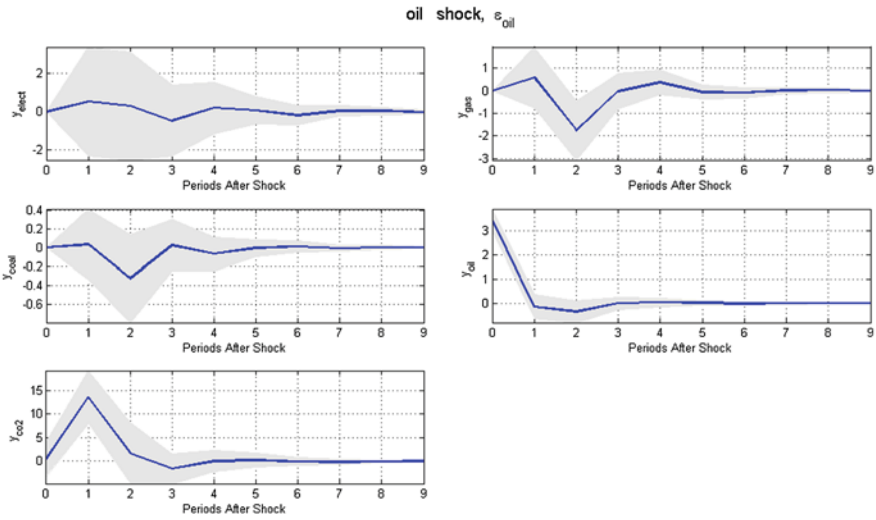

Fig. 3 continued

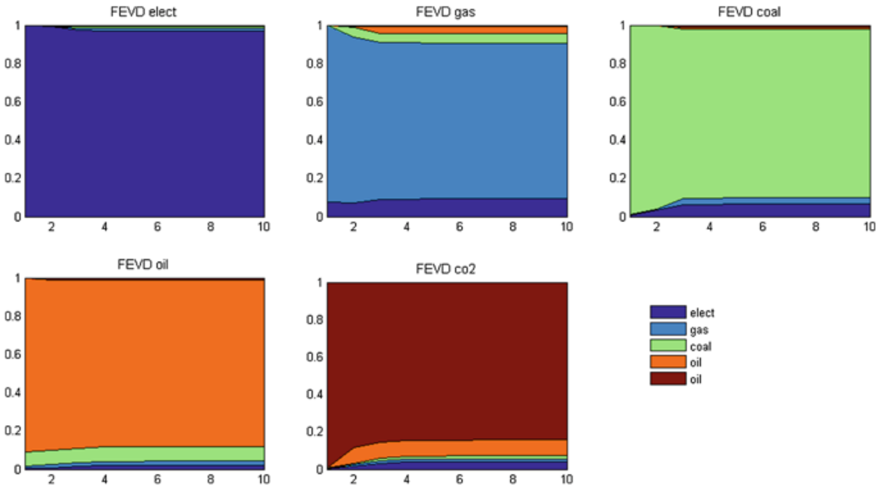

Fig. 4 Forecast error variance decomposition plot for the EEX market. FEVD stands for forecast error variance decomposition of electricity (elect.), gas, coal, oil and carbon (CO_2). The period analysed is January 2009 to July 2012 for the EEX market (corresponding to 148 observations). Values are plotted in relative (%) units. The results of the likelihood ratio (LR) test for lag length in the VAR for EEX (German market) favour the selection of two lags

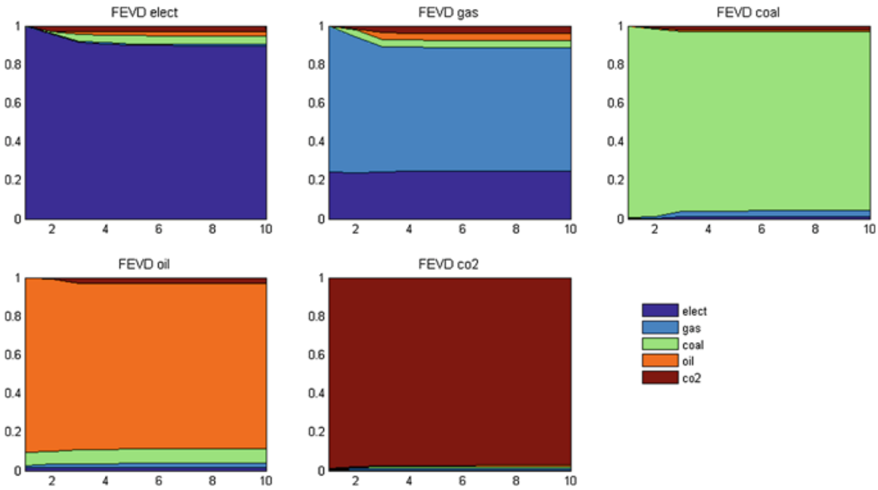

Fig. 5 Forecast error variance decomposition plot for the Powernext market. FEVD stands for forecast error variance decomposition of electricity (elect.), gas, coal, oil and carbon (CO_2). The period analysed is January 2009 to July 2012 for the Powernext market (corresponding to 184 observations). Values are presented in relative (%) units. The results of the likelihood ratio (LR) test and Akaike information criteria (AIC) for lag length in the VAR for Powernext (French market) favour the selection of two lags

equilibrium, be associated with a 1.2 % electricity price rise in the EEX market for a 5 week period (see Table 5).[16] Furthermore, since all coefficients are significant, all price variables are important to define the equilibrium vector.

For the German market, gas, coal and carbon prices may be considered the source of randomness, that represents the main driver of electricity. However, the coal price is the main driver of the source of randomness. Innovations in gas, electricity and carbon play a negligible role in explaining oil prices but the short-term effect increases over time.

Innovation effects in the carbon market to electricity and other fuel markets are null in the short term but the effect increase over time, and are stronger in oil, coal and electricity markets, in this order. Electricity and natural gas explain more uncertainty in coal prices in long horizons.

As we can also see, oil price seems to be mostly explained by coal prices, among the variables considered here (around 7.7 % for all periods). In sum, shocks in the German electricity, gas, coal and oil markets alone are not strong enough to influence the behaviour of the carbon price traded, the impact of which should be explained by factors other than those analysed here. Moreover, none of the fuels and carbon shocks seem to have a short-term effect on electricity, and carbon does

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[16] Endogenous lagged variables were transformed into their natural logarithms to reduce variability, and thus we obtain elasticity values directly from parameter estimates.

Table 5 Forecast error variance decomposition (FEVD) for the EEX market

FEVD of: (variance due to a … shock)	Period/weeks	Elect.	Gas	Coal	Oil	CO_2
Elect.	1	100	7.6	0.6	0.5	0.1
	5	97.0	9.5	6.7	2.1	4.1
	10	96.9	9.6	6.8	2.2	4.1
	20	96.9	9.6	6.8	2.2	4.1
Gas	1	0.0	92.4	0.4	0.9	0.0
	5	1.2	81.2	3.1	2.0	1.3
	10	1.2	81.1	3.1	2.0	1.3
	20	1.2	81.1	3.1	2.0	1.3
Coal	1	0.0	0.0	99.0	7.7	0.4
	5	0.9	4.8	88.2	7.7	1.7
	10	1.0	4.8	88.2	7.7	1.7
	20	1.0	4.8	88.2	7.7	1.7
Oil	1	0.0	0.0	0.0	90.9	0.0
	5	0.1	3.9	1.0	86.8	8.5
	10	0.1	3.9	1.0	86.7	8.5
	20	0.1	3.9	1.0	86.7	8.5
CO_2	1	0.0	0.0	0.0	0.0	99.5
	5	0.7	0.6	1.0	1.3	84.5
	10	0.7	0.6	1.0	1.3	84.3
	20	0.7	0.6	1.0	1.3	84.3

FEVD stands for Forecast Error Variance Decomposition of electricity (elect.), gas, coal, oil and carbon (CO_2). The period analysed goes from January 2009 until July 2012 for the EEX market (corresponding to 148 observations). Values are presented in relative (%) units. The results of the Likelihood ratio (LR) test for lag length in the VAR for EEX (German market), favour the selection of two lags

not seem to be affected by gas, oil and electricity for the 1-week period in the German EEX market.

Our results for the short term (considering 1-week period) in the EEX market can be summarised as follows: gas shocks do not affect electricity and carbon; coal does not affect electricity and gas; oil is not the source of randomness for electricity, gas, coal and carbon; and carbon has a null impact on electricity, gas, coal and oil. Although electricity seems to have a negligible impact on carbon, the effect is null and vice versa.

Turning our attention to the Powernext market, we see that the oil price uncertainty in the French market is explained in the long term mainly by coal prices (7.7 %) and by carbon (3.0 %). However, in France the carbon price uncertainty is mostly explained by coal prices, 1 % for longer periods, followed by natural gas prices and oil. Since natural gas has only residual usage in this market (3.80 % in

Table 6 Forecast error variance decomposition (FEVD) for the French market

FEVD of: (variance due to a … shock)	Period/ months	Elect.	Gas	Coal	Oil	CO_2
Elect.	1	100.0	24.5	0.2	1.4	0.0
	5	90.0	24.8	1.1	1.6	0.4
	10	89.7	24.9	1.1	1.6	0.4
	20	89.7	24.9	1.1	1.6	0.4
Gas	1	0.0	75.5	0.6	1.2	0.3
	5	0.7	63.9	3.1	2.2	0.9
	10	0.8	63.7	3.1	2.2	0.9
	20	0.8	63.7	3.1	2.2	0.9
Coal	1	0.0	0.0	99.2	6.7	0.2
	5	4.2	3.8	92.8	7.4	1.0
	10	4.3	3.9	92.7	7.4	1.0
	20	4.3	3.9	92.7	7.4	1.0
Oil	1	0.0	0.0	0.0	90.7	0.4
	5	1.9	3.6	1.0	85.9	0.5
	10	2.0	3.7	1.0	85.8	0.5
	20	2.0	3.7	1.0	85.8	0.5
CO_2	1	0.0	0.0	0.0	0.0	99.1
	5	3.1	3.9	2.1	3.0	97.2
	10	3.2	3.9	2.1	3.0	97.2
	20	3.2	3.9	2.1	3.0	97.2

FEVD stands for forecast error variance decomposition of electricity (elect.), gas, coal, oil and carbon (CO_2). The period analysed is from January 2009 to July 2012 for the Powernext market (corresponding to 184 observations). Values are presented in relative (%) units. The results of the Likelihood ratio (LR) test and Akaike information criteria (AIC) for lag length in the VAR for Powernext (French market) favour the selection of two lags

2008), innovations in natural gas prices explain only a small percentage of both short and medium/long term carbon prices, which is even more evident for oil (1.35 % in 2008). As also observed here, expanded nuclear power generation could limit increases in electricity prices (Kara et al. 2008; Pinho and Madaleno 2011a) more than in Germany. In France, gas and carbon shocks are the biggest sources of randomness for electricity prices.

While oil and electricity are the major sources of randomness that drive the carbon market for EEX (about 8.5 and 4.1 %, respectively), this is the case of coal and gas in France (1.0 and 0.9 % respectively). Table 6 seems to indicate that coal and carbon are the major sources of randomness for electricity prices for Powernext (4.3 and 3.2 %, respectively), unlike EEX where it is gas and coal (1.2 and 1.0 %, respectively).

As electricity generation in the French market relies mainly on nuclear (77.17 % in 2007), innovations in carbon have an almost negligible impact on electricity prices (Table 6—3.2 %), though it is still higher than that of gas and oil. In fact, from the two markets under analysis, the results of forecast error variance decomposition for the German market seem to indicate that electricity prices hardly react to fuel price and carbon shocks (1.2 % for gas, 1 % for coal, 0.1 % for oil and 0.7 % for CO_2), which confirms the relationship between production source, market structure and electricity price response. These results are consistent with the fact that there has been a large increase in the use of wind for electricity production in the German market in recent years, but this will be addressed in future research due to the current unavailability of data to include this source.

Carbon is not contemporaneous for either market, meaning that 1-week returns (Tables 5 and 6 present a 0 % value for that period) is affected by other energy market. Therefore there are pressures from external factors not captured by the model.

Results reveal the absence of a unified energy market and, contrary to previous literature (Mohammadi 2009), it seems policies related to the coal industry continue to have a marginal influence on electricity, although the impact depends on the country's energy mix (for a more complete analysis see also Pinho and Madaleno 2011a).

On the power generation side, the price of gas affects operating choices more than the price of coal. High gas price encourages a greater use of coal; if everything else remains constant this should increase the demand for CO_2 allowances as coal emits twice the CO_2 content of natural gas. Therefore, if fossil fuels become more expensive, prices of EU ETS are likely to decrease or rise less than otherwise. Moreover, another hypothesis can be explored in this setting. Relationships between energy prices imply the possibility of substitution among the different forms of energy (results would obviously depend upon the country's energy mix).

Additionally, a more competitive market for electricity implies that spot market prices may respond promptly to price changes in input fuel source markets. The French market is the one that most deviates from the desired competition degree. In the EEX, a carbon innovation is reflected less in electricity prices. More recently, sharper increases in the price of allowances have led to speculation that electricity producers might have manipulated the allowance market so as to raise the allowance price, which then triggers an electricity price rise. If producers act as price takers, raising prices artificially is not easy. Since all of them benefit from a price increase, they might collude to manipulate the market and a reduction in market power would be the only solution to reduce speculation.

Moreover, it cannot be assumed that profits from trading in secondary carbon markets finance climate mitigation completely: an increasing number of participants in the carbon market participate to profit from speculation.[17] This trading of the same carbon allowance or carbon derivative takes place mainly among financial speculators who profit from speculating on the volatility of the price of carbon, and not because they are subject to emission reduction targets or have an interest in

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[17] World Bank Carbon Finance Unit (2010): State and Trends of the Carbon Market 2010.

climate mitigation. Increased involvement of speculative actors with no interest in cost-effective implementation of greenhouse gas emission reduction targets may hinder the carbon market achieving its original objective. The motivations of the increasing number of speculative participants in the trading of carbon are opposed to the motivations of those trading to manage their cost of compliance with an emissions target. Participants whose trading is motivated by speculation will use their trading power to generate, exploit and profit from price volatility, as speculators profit from unpredictable price movements. Moreover, linking trading schemes that operate in jurisdictions where the enforcement capacity differs significantly will provide further ground for trading in "subprime" carbon derivatives in particular, given that much of the trading activity in carbon offsets takes place over-the-counter.

Even though the EU-Directive on trade of CO_2 allowances is a promising step, much more needs to be done to reach the ideal system. First, national governments in the EU allocate the CO_2 allowances in different ways; some are more generous than others and there is a natural influence of lobbying. Second, outside the EU there is no such system of allocation so that CO_2 intensive industries outside the EU have no incentive to economise on their CO_2 emissions. In that case, cooperation between EU and non-EU companies could result in additional allowances. Production technologies for electricity differ greatly in their CO_2 emissions and it proves difficult to reduce the aggregate level of emissions by governmental directives.

It can also be questioned whether allowances price act as reliable price signals for companies to invest in less CO_2 intensive production technologies. If a company uses these desirable technologies, it may not be awarded allowances in the future so that it cannot sell these and gain additional profits. Thus, the net benefit from switching to a technology without CO_2 emissions is dubious. Moreover, reducing the use of CO_2 intensive technologies would foster the debate on the use of nuclear energy.

5 Conclusions

In this chapter, we analyse the relationships between electricity prices, primary energies prices used in electricity generation and the price of carbon dioxide emission permits in France and Germany using a VECM model. The difference in responses to carbon constraints in the electricity generation sector were accounted and allowed us to of the EU ETS given the energy mix heterogeneity of both countries for the Phase II period.

We were able to show that the impact of carbon constraints on energy markets depends on the countries' energy mix. This allows us to conclude that it is not always producers in countries using predominantly fossil fuels, which are great carbon emitters, that undertake more carbon coercion; results indicate that they do not necessarily include the price of emission permits in their electricity generation and cost functions (EEX). Using other sources of electricity production like wind might have helped us obtain more useful results to explain this. We also found that oil and electricity are the major sources of randomness that drive the carbon market for EEX, but not vice versa given that it is coal that most impacts oil, and gas that most impacts electricity. Furthermore, natural gas is significantly affected by electricity in both the short and the long term. We also found that coal and gas have the biggest impact on electricity prices.

Coal and gas are the major sources of randomness for carbon in France; however, coal is mostly affected by gas, and gas by electricity in this market. Whereas carbon is the major source of randomness for electricity and gas in Powernext, this is the case for coal and oil in EEX. For Powernext, we also found that coal and carbon have the biggest impact on electricity prices. Also, coal is mostly used as a power source in EEX and explains carbon better in this market than in Powernext. However, carbon explains coal more in Powernext than in EEX.

Hitherto, it has been understood that policies related to the coal industry have a marginal influence on electricity prices. Empirical results seem to show that policies towards clean air still do not imply a rise in the cost of coal and electricity production, but we have also seen that the coal market is the major source of randomness for oil prices in both France and Germany. Throughout the period analysed, the efficiency of the European market for emission allowances was therefore unable to compel electricity producers to eliminate their emissions and invest in cleaner technologies, whereas the desired effects also depended on policies pursued for distributing allowances.

Given that CO_2 markets are relatively new markets, we could improve the quality of results by repeating the analysis some years from now because more data becomes available as markets evolve. In addition, it would be productive to use daily data which is currently impossible due to data restrictions. Moreover, portfolio analysis using these different commodities from a trader's point of view could offer valuable insights into necessary strategies for these markets.

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