Permit Price Dynamics in the U.S SO2 Trading Scheme: a Cointegration Approach

PRELIMINARY VERSION

Mohamed Amine Boutaba*, Olivier Beaumais*, Sandrine Lardic**

June, 2008

Abstract: The aim of this paper is to study empirically the determination and the dynamic behaviour of the SO2 permit prices. Previous research focused on ex-post market price analysis without taking weather conditions into account. Therefore, this study attempts to fill a gap in the literature by providing new empirical evidence on the SO2 price evolution and its interactions with macroeconomic variables, microeconomic variables and climate variables. Using monthly data from January 1995 to December 2006, our estimation results indicate the existence of a long-term relationship between SO2 permit price, the three-month treasury constant maturity rate and weather conditions. In the short run, SO2 permit price is mostly affected by scrubbing costs, the three-month treasury constant maturity rate and weather conditions. The empirical evidence suggests the stability of our model for the whole period in the long-and short-run which would make possible the forecasting of SO2 permit price.

Keywords: SO2 emission permits, Price fundamentals.

JEL Classification: Q52, Q53, C22, C32.

* CARE (Centre d'Analyse et de Recherche en Économie), University of Rouen, UFR Droit-Économie-Gestion, 3, avenue Pasteur, 76186 Rouen cedex, France.
** EconomiX-CNRS, University of Paris 10, UFR SEGMI, 200 avenue de la République, 92001 Nanterre cedex.

E-mail adresses : mohamedamine.boutaba@univ-rouen.fr (M.A. Boutaba), olivier.beaumais@univ-rouen.fr (O. Beaumais), Sandrine.Lardic@u-paris10.fr (S. Lardic).

1. Introduction

The use of tradable emission permits as market-based environmental policy instruments has gained increasing attention by both policy makers and regulators in recent years. This policy instrument has emerged as a practical tool for cost-effective pollution control mainly since the seventies. However, the SO2 allowance trading program, created by the Clean Air Act Amendments of 1990, is the first large scale use of such instruments in environmental policy. The tradable emission permits have become an increasingly accepted environmental approach in many countries as the US SO2 program has resulted in significant SO2 emissions reductions and far lower-than-expected compliance costs (Ellerman, Joskow, Schmalensee, Montero and Bailey, 2000; Carlson, Burtraw, Cropper and Palmer, 2000) and human health benefits (Chestnut and Mills, 2005). Indeed, the European Union has established a cap-and-trade program for greenhouse gases, and other countries such as Austria, Japan, Chile, Korea and New Zealand are considering the use of such programs to control pollution.

The general behaviour of prices in cap-and-trade programs has already attracted great interest in the environmental economics literature. As it is well known from this literature, under usual conditions, an allowance market leads to the equalization of the marginal costs of abatement and emission permits prices. If a participant has a low abatement cost, that participant can reduce below its allowance allocation and sell the remaining allowances or simply bank them for future use. However, there has been relatively little empirical research with an explicit focus on the formation and the dynamic behaviour of the price of emission permits. At present the CO2 market is immature and consequently the existing data do not permit to explain efficiently the movement and formation of the CO2 price. On the contrary, the SO2 permit market is the most mature of present emissions trading schemes and has consequently sufficient price history to analyse the SO2 spot price process.

Using industrial organization model, Schennach (2000) analyses the optimal banking behaviour of generating units and incorporate certainty and uncertainty into her analytical framework. However, she shows no interest in the dynamic of the spot price behaviour. Under certainty, the model predicts that the price path follows Hotelling's rule, increasing at the rate of interest. Under uncertainty, she observes that the expected price path of the SO2 permit price can rise at a rate less than the discount rate even when the bank is not expected to be empty. Ellerman and Montero (2007) follow the approach put forward by Slade and Thille (1997), who combined the Hotelling model for the price of exhaustible resources with the capital asset pricing model (CAPM) for risky assets, to model the efficient path of SO2 allowance banking and implicitly the evolution of allowances prices using simulation methods. They find that the time pattern of the allowance banking has been reasonably efficient. Kosobud, Stokes, Tallarico and Scott (2005) demonstrate, on the basis of time series data, that SO2 emission permits have positive rates of return and yield distributions. In addition, they find no significant correlation between SO2 returns and returns from various financial investments, suggesting that SO2 permits may be included in a diversified portfolio. Helfand, Moore and Liu (2007) follow Shennach's (2000) theoretical model of the intertemporal SO2 market in addition with the Hotelling model to analyse SO2 price movements from august 1994 to December 2003 using econometric methods. They find that SO2 price movements depend on the risk-free interest rate, excess returns to the stock market portfolio, and several unexpected shocks in SO2-related markets.

The aim of this paper is to study empirically the determination and the dynamic behaviour of the SO2 permit prices. Previous research focused on ex-post market price analysis without taking weather conditions into account. Therefore, this study attempts to fill a gap in the literature by providing new empirical evidence on the SO2 price evolution and its interactions with macroeconomic variables, microeconomic variables and climate variables. Using monthly data from January 1995 to December 2006, our estimation results indicate the existence of a long-term relationship between SO2 permit price, the three-month treasury constant maturity rate and weather conditions. In the short run, SO2 permit price is mostly affected by weather. The empirical evidence suggests the stability of our model for the whole period in the long-and short-run which would make possible the forecasting of SO2 prices.

The remainder of the paper is organized as follows: Section 2 describes the SO2 allowance market. Section 3 provides a brief review of the existing literature on SO2 allowance fundamentals. Section 4 describes the data used in the study. Section 5 presents the empirical results and section 6 concludes.

2. Background

The acid rain program was designed to cut the adverse effects of acid rain by reducing electric power sector emissions of SO2. Total annual emissions are mandated to be reduced by 10 millions tons below 1980 levels by the year 2000. Aiming to achieve this reduction, a market for SO2 allowances or permits was created. Each allowance grants its possessor the right to emit one ton of SO2 and can be used the year of its issue, banked for use in later years, or sold if the generating unit emits less than its allocation. In the first phase of the program from 1995 to 1999, the 263 of the most polluting coal-fired electricity generating units with an output capacity greater than 100 megawatts (MW), which belong to 110 power plants located in 21 eastern and mid-western states — the so-called "Table A units" — are allocated a fixed number of allowances each year sufficient for an average emission rate of 2.5 pounds SO2 per million Btu of average 1985-1987 heat input. Power plants may select units not originally affected until phase II to enter the program early as substituting or compensating units to help fulfil the compliance obligations for "Table A units" targeted by phase I. In addition, industrial emission sources, such as refineries and smelters, may voluntarily enter the program if they feel they can make emissions reduction at low cost (opt-in units). The second phase, which began in the year 2000 and continuing indefinitely, covers the remaining generating units fired by coal, oil and gas with an output capacity greater than 25 MW, which are allocated allowances sufficient for a more stringent average rate of 1.2 pounds of SO2 per million Btu of average 1985-1987 heat input. In both phases, allowances are allocated to units in proportion to emissions over the three years 1985-1987 base period. The SO2 cap-and-trade system appeared effective only from the moment it rested on a powerful system of measure and recording of SO2 emissions (*The Allowance Tracking System*) maintained by the Environmental Protection Agency (EPA) and on stringent penalties[1] incurred by generating units if total emissions at these units exceed the number of allowances after 30 days following the end of each year. Several studies have attempted to assess the efficiency of the SO2 allowance market. Mounting evidence has shown that the market is becoming efficient over time. This is shown in the work of Joskow, Schmalensee and Bailey (1998), Carlson, Burtraw,

[1] The Clean Air Act Amendments set a penalty of $ 2.000 per ton in 1990, which is adjusted annually for inflation. The 2006 penalty level was set at $ 3.152 per excess ton (EPA Progress Report, 2006).

Cropper and Palmer (2000), Arimura (2003), Ellerman and Montero (2007), Keohane (2006) and Helfand, Moore and Liu (2007).

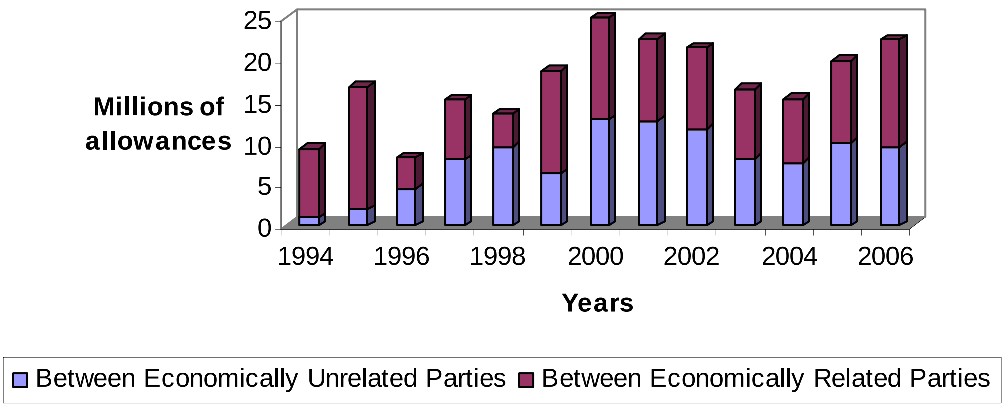
At present, the SO2 market has a fifteen year price history. Since 1993, an auction of approximately 2.8% of the total annual allowances was conducted on behalf the EPA by the Chicago Board of Trade[2] (CBoT). This auction is supposed to increase liquidity in the market, provide a price signal for private trades and an assured source of allowance supply. Before passage of the Clean Air Act Amendments of 1990, EPA experts estimated allowances prices to be as high as $ 1.500, which was the price fixed (adjusted for inflation) for direct sales by the EPA. Hahn and May (1994) reported pre-1992 estimates of forecasted SO2 allowances prices ranging from 302$ (Allegheny Power System) to 981$ (united Mine Workers) for the first phase and from 374$ (Resource Data International) to 981$ for the second phase (United Mine Workers). However, the clearing price of the 1995 vintage allowances in the first and the second EPA auction was respectively 131$ and 150$. The difference between expected prices and the observed prices was mainly due to the important role of expectation errors and the irreversibility of many compliance options that have an increasing effect upon prices (Ellerman and Montero, 1998a; Ellerman and Montero, 1998b; Ellerman, Joskow, Schmalensee, Montero and Bailey, 2000 and Carlson, Burtraw, Cropper and Karen, 2000). Since the cash market became better established, the CBoT has offer swaps, option and future contracts for the SO2 allowance market. Later years, the New York Mercantile Exchange (NYMEX) and the Chicago Climate Exchange (CCX) have also created futures markets for allowances. These contracts have enabled market participants to hedge the financial risks associated with future unforeseen changes in allowances prices.

As shown in figure 1, the allowance trading volume has been significant only by the year 1995. Indeed, nearly 613 private allowance transfers affecting roughly 16.7 million allowances were recorded in the EPA Allowance Tracking System. Of the allowances transferred, 1.9 million (11.38%) were transferred between economically unrelated parties[3] . In the first phase of the program, the allowance trading volume between economically distinct parties was substantially increased from year to year, suggesting that firms are taking advantage of the cost-saving opportunities provided by emissions trading (Ellerman, 2003). During 2000, the volume of transferred allowances between economically unrelated parties jumped to above 12 million allowances and has declined each year to close to 7.5 million allowances in 2004. This decline of the market liquidity is mainly due to the bankruptcy of Enron in late 2001, which buffeted trading in the related electricity markets (EPA Progress Report, 2006). In 2006, almost 6400 private allowance transfers corresponding roughly to 22.4 million allowances happened in the market. About 9.5 million (42.41%) were transferred in economically significant transactions. Since 1996, the volume of private transfers between economically unrelated parties was in range from 33.2% to 70.4% of the total volume of transactions. Given the sufficient significance of the volume of interplant trading, the SO2 allowance market is thus reasonably liquid.

[2] CBoT received no compensation for the service, nor was it allowed to charge fees. Beginning in March 2006, CBoT decided to stop administering the auctions, resulting in EPA now conducting them directly.

[3] "Transfers between economically unrelated parties are considered a better indicator of liquid and vibrant markets than are transactions among the various units of a given plant" (US EPA Progress Reports 1995-2006).

Fig. 1. SO2 Allowances Transferred under the Acid Rain Program



Source: US EPA Progress Reports 1995-2006.

3. SO2 allowance market fundamentals: a literature review

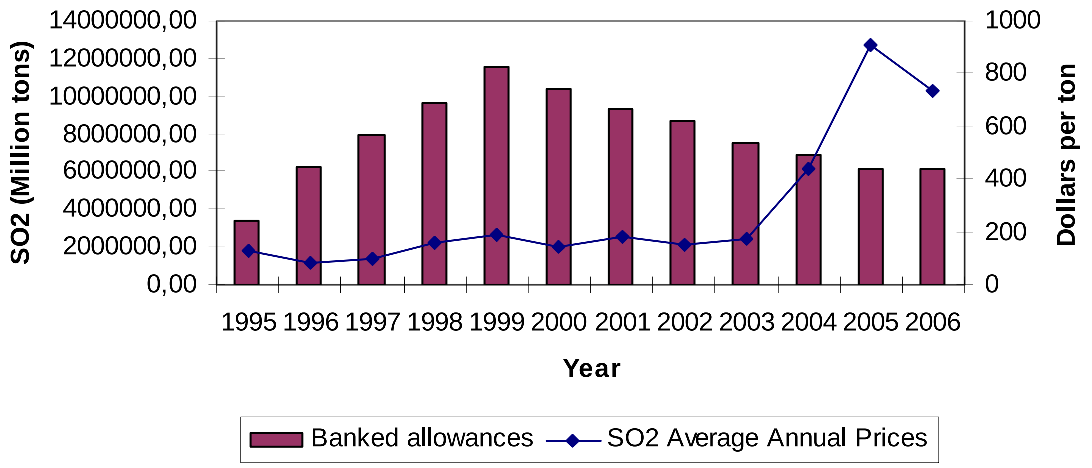
A straightforward way to identify the SO2 allowance price fundamentals is to figure out the main factors that affect supply and demand of allowances.

3.1. Supply factors

The supply of allowances is mainly influenced by the stringency of caps required from generating electric plants, which is a function of the initial allocation. Therefore, a tightening of SO2 emission limits can cause upward pressure on allowances prices. Using an output distance function approach to estimate the marginal abatement cost at Wisconsin coal-fired utility plants, Coggins and Swinton (1996) find that the average price of marginal reduction in SO2 emissions is $ 292.70 in constant 1992 dollars. They note that this marginal abatement cost is higher than allowance prices at which the few observed trades have occurred, suggesting that the difference can be explained by the stringent local SO2 emissions rules which require an emission rate no more than 1.2 pounds of SO2 per mmbtu of heat input by 1993. In addition, on March 2005, following the success of the CAAA of 1990, the US EPA promulgated the *Clean Air Interstate Rule* (CAIR) that will dramatically reduce the SO2 emissions that moves across the boundaries in 28 eastern states and the District of Columbia in 2010. This rule establishes a cap-and-trade system that will abate SO2 emissions by over 70 percent in 2015 from 2003 levels. As SO2 emissions cap is tightened, it would expect in theory that the average cost of emissions reductions to always rise.

Banking is also a relevant determinant of the SO2 market price. Godby, Mestelman, Muller and Wetland (1997), Mestelman, Moir and Muller (1999) and Cason and Gangadharan (2006) show the important role of banking to smooth out the price volatility of allowances. They highlight that banking allows efficiency gains to be achieved by equalizing marginal abatement costs across generating utility plants. Ellerman (2003) and Ellerman and Montero (2007) conclude that the level of banking in Phase I was not excessive but it reflect rather the rational behaviour of the affected utility generating units provided by the change in total emissions between 1999 and 2000, when the allocation of allowances for affected units was reduced by 50%. Given the decrease of the accumulated allowance bank was concomitant with the start of the increase of allowance prices (see Figure 2), it is plausible that the declining allowance banking boosted allowances prices as it make more generating units reliant on the allowance market. Similarly, given that banked from the Acid Rain Program can be used for compliance of the CAIR rule, there is strong evidence that generating units has already begun to factor the future value of the banked allowances today, thus increasing the SO2 permit prices.

Fig. 2. SO2 Average Annual Prices and the Allowance Bank



Source: US EPA and Cantor Fitzgerald

3.2. Demand Factors

Fluctuations in the consumption of SO2 allowances are primarily driven by state and Public Utility Commission (PUC) regulatory developments[4]. In general, some of these rules required the installation of scrubbers and other attempt to allow cost recovery, pre-approval or return on investment of the costs of particular compliance options and prohibited utilities to retain a certain percentage of revenues from allowances sales. The goal of these actions is mainly to promote local activity and protect employment in the mining of the high-sulfur coal within the state. Therefore, these rules discourage allowance trading in favour of other compliance options, thus decreasing the price of allowances. Several studies show that public utility regulations and other state laws have influenced the cost of compliance and implicitly SO2 allowance prices. Bernstein, Farrell and Winebrike (1994), Winebrake, Farrell and Bernstein (1995) and Fullerton, Mc Dermott and Caulkins (1997) evaluate the cost of regulatory interventions which restrict trading in some state and find that restrictions increase substantially the cost of compliance. They find also that costs under a system of tradable permits are higher than costs under a traditional command-and-control strategy. Arimura (2002) examines the effects of PUC regulations on the choice of compliance methods (fuel switching/blending or additional allowance purchase) under SO2 allowance market using data of 1993. He finds that cost recovery rules encourage high sulfur coal use for generating units located in states with high-sulfur coal. His probit model shows that regulations lead these units to pursue a self-efficient strategy of fuel switching/blending in compliance. He finds also that the PUC regulations are stronger than high-sulfur coal protection law. Mizobuchi

[4] For a description of these rules, see Rose, Taylor, and Harunuzzaman (1993), Bohi (1994), Rose (1997), and Lile and Burtraw (1998).

(2004) modifies Arimura (2002) model and examine the effect of PUC regulations from 1995 to 2001. He finds similar evidence of the strength of PUC regulations at the beginning of the SO2 cap-and-trade program but he show that the high sulfur coal protection regulation effect become more strong in phases I and II. Sotkiewicz (2002) and Sotkiewicz and Holt (2005) attempt to quantify the effect of PUC regulatory rules on the ability of cap-and-trade emissions program to achieve least-cost abatement and maximum cost-savings. Their model includes data for the 431 generating units that participated in the SO2 program in 1996. The simulation results show that PUC regulatory rules can induce generating units to deviate from cost-minimizing behaviour.

The reduction in scrubbing costs per ton has contributed to the reluctance to trade allowances. Burtraw (1996, 2000), Carlson, Burtraw, Cropper and Palmer (2000) and Ellerman, Joskow, Schmalensee, Montero and Bailey (2000) find that flexibility afforded by the trading program has encouraged the installation of scrubbers with high removal efficiencies which contribute to the decline in scrubbers costs and, thus an increase in the use of scrubbers. Keohane (2003) find also that scrubbing costs decrease with abatement, noting that such scale economies of utilisation appear to be greater at the retrofitted scrubbers. Popps (2003) find similar evidence of the role played by allowance market to increase improvement in the SO2 removal efficiency of scrubbers.

An increase in relative low-sulfur fuel prices is expected to boost SO2 allowance prices in the short run, if it is substituted by high-sulfur fuel. If such prices increase is sustained in the long run, the price effect prevails upon the substitution effect and therefore SO2 prices decrease via the reduction in energy demand. The relative marginal costs of fuel switching and innovation in fuel blending[5] could affect positively SO2 allowance prices. The dominant factor that has encouraged substitution between coals is the price decline of low-sulfur coal explained by the decrease in mining costs (Kunce, Hamilton and Gerking, 2005) and the decline in railroad shipping costs (Ellerman and Montero, 1998b) due to the deregulation of the railroads under the Staggers Act of 1980. In addition, the increase of natural gas and dual-fueled capacity (generators that burn either natural gas or coal) which increased the flexibility to switch among coal and gas-fired power generation makes the effect of marginal coal-gas switching costs more significant over time.

Weather conditions may affect positively SO2 prices via electricity consumption. Indeed, several studies, notably Le compte and Warren (1981), Engle, Granger, Rice and Weiss (1986), Peirson and Henley (1994), and Considine (2000) have outlined the closer relationship between electricity demand and weather. Although previous studies do not account for this variable to explain SO2 prices movement.

The composition of the Net generation electricity by energy source is bound to affect allowance prices via allowance demand. Given that nuclear generation is the second-largest source of electricity supply, the availability of nuclear generation often displaces the use of fossil fuels because of its low production cost. Similarly, hydroelectric generation which is the largest component of renewable electricity generation and exhibits the lowest production cost in that category could also influence negatively the use of fossil fuels. Indeed, substantially less precipitation that reduce hydroelectric power production make an increase of power production from coal plants, and as results SO2 emissions and SO2 permit prices tend to raise.

[5] For more details on fuel blending and switching costs, see International Energy Agency (1993) and U.S. Energy Information Administration (1994), respectively.

Finally, economic growth could also affect positively allowances prices because of the causal interactions between economic growth and electricity demand (Kraft and Kraft, 1978; Helfand, Moore and Liu, 2007). Table. 1. summarizes the different factors and their expected impacts on SO2 prices.

Table. 1. Summary of SO2 price fundamentals

Factor	Impact on SO2
* Supply factors:	
- Initial allocation	-
- Banking of permits	-
* Demand factors:	
- State and PUC regulation that restrict allowance trading	-
- Operating scrubber costs	+
- Low-sulfur coal, high-sulfur coal, petroleum and natural gas	-
- Relative prices of low-sulfur coal	+/-
- Relative prices of natural gas	+/-
- Marginal coals-switching costs	+
- Marginal gas-coal switching costs	+
- Extreme temperatures	+
- Nuclear generation	-
- Hydroelectric generation	-
- Economic growth	+

Source: Coggins and Swinton (1996), Godby, Mestelman, Muller and Wetland (1997), Mestelman, Moir and Muller (1999), Cason and Gangadharan (2006), Bernstein, Farrell and Winebrike (1994), Winebrake, Farrell and Bernstein (1995), Fullerton, Mc Dermott and Caulkins (1997), Arimura (2002), Mizobuchi (2004), Sotkiewicz (2002) and Sotkiewicz and Holt (2005), Burtraw (1996, 2000), Carlson, Burtraw, Cropper and Palmer (2000), Ellerman, Montero, Joskow, Schmalensee, and Bailey (2000), Keohane (2003), Popps (2003) Ellerman and Montero (1998b), Zhang (2006), Le compte and Warren (1981), Engle, Granger, Rice and Weiss (1986), Peirson and Henley (1994), and Considine (2000), Kraft and Kraft (1978), Chicago Climate Exchange (2004), Helfand, Moore and Liu (2007).

4. Data

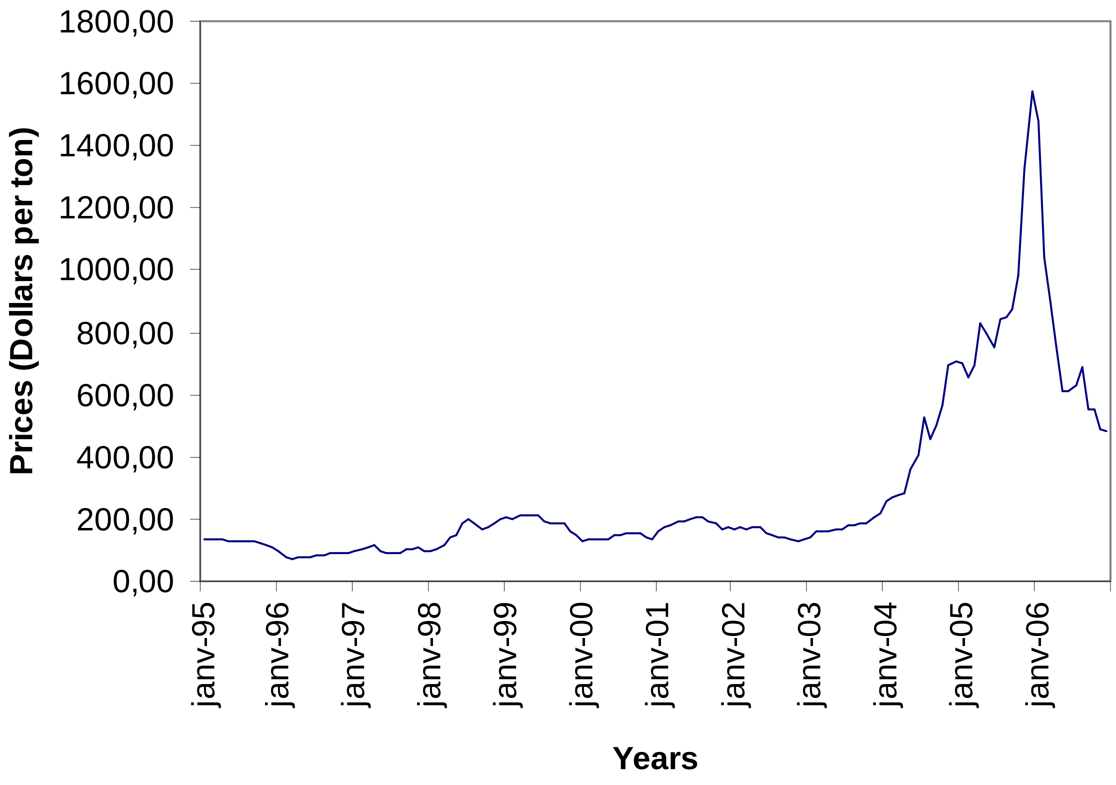
Our analysis is based on monthly data covering the period of 1995-2006. Table 2 summarizes the data, its construction and relevant data sources. The data considers the spot market price for SO2 permit, average overhead and maintenance costs of flue gas desulfurization units (scrubber), spot market prices for low-and-high-sulfur coal, relative low-sulfur coal prices, the spot market price for natural gas, the spot market price for petroleum, the consumer price index, the spot market price for electricity, the volume of banked permits, the nuclear net generation, the industrial production index, the three-month treasury constant maturity rate, and total monthly degree-days.

Table. 2. Data and sources

Series	Specifications	Source
SO2	Spot market price for SO2 permit ($/ton)	Cantor Fitzgerald
AOMCS	Average overhead and maintenance costs (mills per kilowatthour)	Energy Information Administration
LSC	Spot market price for low-sulfur coal ($/mmbtu)	Energy Information Administration
HSC	Spot market price for high-sulfur coal ($/mmbtu)	Energy Information Administration
LHSC	Relative low-sulfur coal prices ($/mmbtu) = LSC/HSC	Energy Information Administration (Authors calculation)
NG	Spot market price for natural gas ($/mmbtu)	Energy Information Administration (Authors calculation)
PET	Spot market price for petroleum ($/mmbtu)	Energy Information Administration (Authors calculation)
CPI	Consumer price index	Federal Reserve Bank of ST. Louis
ELEC	Spot market price for electricity ($/Kilowatthour)	Energy Information Administration
BP	Banked permits (ton)	US Environnemental Protection Agency
NUCNG	Nuclear net generation (Thousand Megawatthour)	Energy Information Administration
IPI	Industrial production index (year 2002 = 100)	Federal Reserve Bank of ST. Louis
TC3M	Three-month treasury constant maturity rate	Federal Reserve Bank of ST. Louis
HDD	Monthly heating degree-days (Fahrenheit)	US National Climatic Data Center
CDD	Monthly cooling degree-days (Fahrenheit)	US National Climatic Data Center
HCDD	Total monthly degree-days (Fahrenheit) = HDD+CDD	US National Climatic Data Center (Authors calculation)

The spot market prices for SO2 permit are taken from the brokerage firm Cantor Fitzgerald which calculates it as an average of permit prices on bids to buy and offer to sell for current vintages of permits. Fig. 3 displays the price trend of permits during the 1995-2006 period. The price of a permit has dropped from $ 137 per ton at the beginning of the program to a low of just $ 70 in March 1996. Following this decline, the price climbed over $ 190 per ton by the end of 1998. In 1999, prices rose temporarily above $ 200 due partially to the planning for the more stringent phase II. During the second half of 2000, prices dropped down again to $ 130 per ton but showed signs of a rebound at the very end of the year and remained relatively steady through 2003. However, the price of permit increased sharply during 2004-2005 period, ending the period at about $1578.11 per ton after beginning the price at about $ 260 per ton. This increase is due to initial uncertainties as EPA finalized the Clean Air Interstate Rule. This rule requires further SO2 reductions from generating units in many eastern states beginning in 2010. These additional reductions put upward pressures on the expected marginal cost of compliance in future years and therefore, affect the market price of permits. In 2006, however, permit prices has fallen sharply ending the year at about $480, due in part to dramatic increase in average temperatures which makes 2006 the warmest year on record and to the self-correction of the expected marginal cost of reducing SO2 emissions under CAIR as buyer and sellers were more completely assessed market fundamentals.

Fig. 3. The Evolution of SO2 Permit Prices



Source: Cantor Fitzgerald

The average overhead and maintenance costs are obtained from the responses from electric utilities survey Form EIA-767, “the Steam-Electric Plant Operation and Design Report”. These costs include direct costs such as operating and maintenance staff labor, replacement materials, and indirect costs such as overhead, insurance and administration. The volume of permit banked is gathered from US EPA Progress Reports 1995-2006. Both data are available on annual frequency[6]. We used linear interpolation method to change them into monthly frequency.

To construct data on spot prices for low-and-high-sulfur coal, petroleum and natural gas, we used data collected from EIA 423-Database “the Monthly Report of cost and Quality of Fuels for Electric Plants”. This database records delivered cost, sulfur content, ash content, heat content (mmbtu), quantity and the type of contract purchases of each fuel transaction at each electric plant. The EIA 423 contains coal type that has for categories: bituminous, subbituminous, anthracite and lignite. We used data for spot purchases. Between January,

[6] The average overhead and maintenance costs are not available in 2006. We multiplied its value in 2005 by the variation rate between 2004 and 2005 to obtain an approximation of the average overhead and maintenance costs in 2006.

1995 and December, 1999, we used data only from "Table A plants"[7]. After 1999, we used data from all plants. Following Carlson, Burtraw, Cropper and Palmer (2000), a SO2 emission boundary of 1.2 pounds of SO2 per mmbtu of heat input was used to distinguish low-and-high sulfur coal. Given that the data set provides only sulfur (S) content, we use the following formula obtained from Helfand, Moore and Liu (2007) to compute SO2 content:

$$\frac{S\,content}{SO2\,content} * 10.000 * conversion\ factor\ appropriate\ for\ the\ coal = pounds\ SO2 / mmbtu$$

The factors are 1.91 for bituminous coal and 1.76 for subbituminous coal. Because conversion factors are not available for anthracite and lignite, we eliminated these types of coal when distinguishing between the two types of coal. The part of Anthracite and lignite in total tons of coals has ranged roughly from 0.045 to 0.091 in 1995-2006 period. Prices of coals, natural gas and petroleum are the weighted average costs in $ per mmbtu, and is calculated using the following formula[8]:

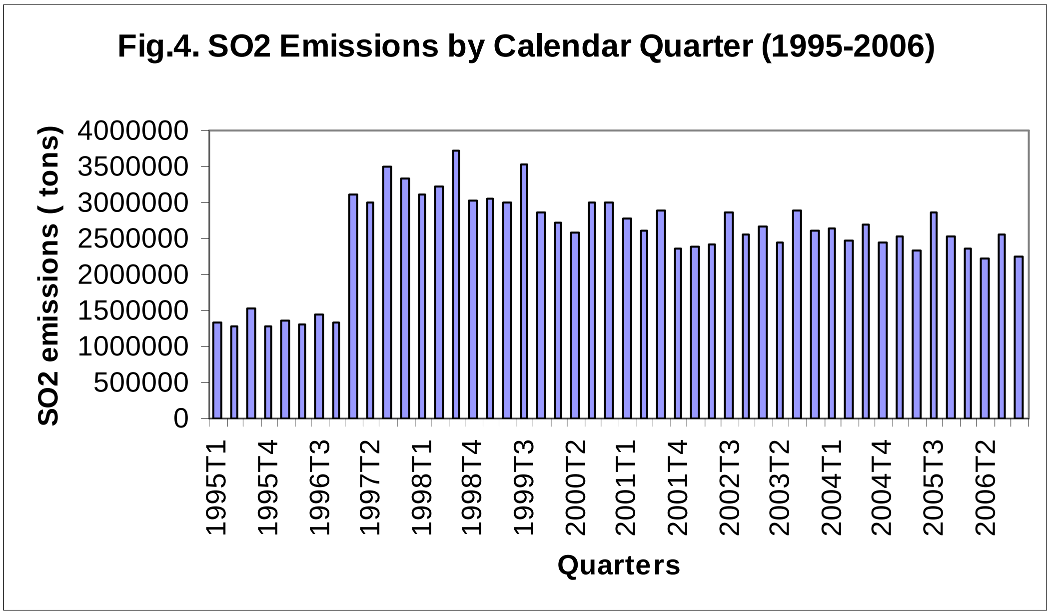
$$Weighted\ Average\ Cost = \frac{\sum_i (R_i A_i C_i)}{\sum_i (R_i A_i)}$$

where *i* denotes a plant; R_i = receipts for plant *i*, A_i = average heat content for receipts at plant *i*; and, C_i = cost in $ per mmbtu for plant *i*.

Industrial production index, three-month treasury constant maturity rate and consumer price index are obtained from Federal Reserve Bank of ST. Louis. Spot market prices for electricity and nuclear net generation are taken from Electric Power Monthly Reports 1995-2007. The latter variable represents the amount of gross nuclear generation less the electrical energy consumed at the generating station for station service or auxiliaries.

As shown in the Fig 4, the relationship between temperature and SO2 emissions is highly nonlinear, because electricity consumption increases at both low temperatures (inducing electricity use for heating) and high temperatures (causing air conditioner operation for cooling). Hence, the appropriate climate variable to assess SO2 allowance prices is total monthly degree-days (HCDD) which is the sum of monthly heating and cooling degree-days. Monthly heating degree-days function is defined as $HDD_t = \sum_t \max(T_{ref} - T_t, 0)$ and monthly cooling degree-days function is defined as $CDD_t = \sum_t \max(T_t - T_{ref}, 0)$, where T_t is the daily average temperatures and T_{ref} is a reference temperature of 65° F which separate the cold and heat branches of the demand temperature relationship. Heating and cooling degree-days measure the intensity and duration of cold or heat in winter and summer days, respectively. Total monthly degree-days are 1990 population-weighted averages of U.S. regions weather data.

[7] The list of "Table A plants" is available on the EPA website: http://www.epa/air/caa/caa404.txt.
[8] This formula is taken from Electric Power Monthly Reports 1994-2007.



Source: US EPA

Spot market price for electricity, nuclear net generation and total monthly degree-days are seasonally adjusted. We use the natural logarithm for all variables. Table 3 provides the descriptive statistics of the series used in the model.

Table. 3. Descriptive statistics

	SO2	AOMCS	LSC	HSC	LHSC	NG	PET
Mean	2.311	0.061	0.117	0.141	-0.024	0.593	0.638
Maximum	3.198	0.139	0.303	0.361	0.080	1.084	1.050
Minimum	1.841	-0.018	0.012	0.038	-0.194	0.202	0.204
Std. Dev.	0.318	0.032	0.081	0.120	0.053	1.975	0.155

	CPI	ELEC	BP	NUCNG	IPI	TC3M	HCDD
Mean	5.160	0.859	6.865	1.672	1.988	0.530	2.622
Maximum	5.318	0.948	7.065	1.802	2.051	0.806	2.720
Minimum	5.013	0.817	6.536	1.521	1.898	-0.067	2.525
Std. Dev.	0.086	0.036	0.144	0.085	0.042	0.266	0.036

5. Empirical results

5.1. Unit root tests

Unit root test results are needed to verify the order of integration of the variables since the cointegration test is valid only if the majority of the variables have the same order of integration. In order to have robust results, we conducted 4 different unit root tests, namely Augmented Dickey–Fuller (1979, 1981) (ADF), Phillips–Perron (1987) (PP), Kwiatkowski–Phillips–Schmidt–Shin (1992) (KPSS), and Zivot and Andrews (1992) (ZA) test. ADF and PP tests have a null hypothesis stating that the series in question has a unit root against the alternative that it does not. The null of KPSS, on the other hand, states that the variable is stationary. In the literature, KPSS is sometimes used to verify the results of ADF and PP because their probability of rejecting the false hypothesis is low. Perron (1989) shows that conventional tests (ADF and PP) is subject to misspecification bias and size distortion when the series involved structural shifts which leads to a falsely failure to reject the unit root hypothesis. Perron (1989) develop procedure that test for a unit root allowing for a one-time structural change in the trend. But Perron (1989)'s test has been criticised for treating the time of break as exogenous. To capture the effect of any possible structural break over the estimation period, the ZA unit root test is used, which is a transformation of Perron (1989)'s unit-root test treating endogenously the presence of any possible break in the series. In the estimation, we allow both the break points and the lag length to vary endogenously. The null hypothesis is that the variables contain a unit root with a drift that excludes any structural break. The alternative hypothesis is that the series is a trend-stationary process in which a one-time break in the trend variable occurs at an unknown point in time. The results of the unit root tests in Table 4 shows that most of the variables are non stationary and integrated of order 1, except for the LHSC, NG and HCDD series. Table 5 reports the minimum t-statistics from testing the stationary trend. The minimum t-statistics is the minimum overall break point regressions from 1995:1 to 2006:12. The results show that at 5% level of significance SO2, BP, and TC3M are non stationary. The estimated breakpoint for SO2 series is in April, 2004. It coincides with the proposition of the CAIR by the EPA in January, 2004. The estimated breakpoint for BP series is in January, 2000, which is concomitant with the start of a more stringent phase of SO2 reductions. The estimated breakpoint for TC3M series is in May, 2004, which is related to the raise in the benchmark federal funds rate.

Table. 4. Unit root test to individual series

Series in logarithms	**ADF**		**PP**		**KPSS**	
	Level	First Difference	Level	First Difference	Level	First Difference
	Test statistics	Test statistics	Test statistics	Test statistics	Test statistics	Test statistics
AOMCS	-2.88 (2)	-3.03* (1)	-1.03 (1)	-3.21* (1)	0.59* (3)	0.08 (3)
LHSC	-2.70* (2)	-	-5.74* (3)	-	0.07 (3)	-
NG	-3.81* (3)	-	0.18* (2)	-	0.06 (3)	-
PET	0.51 (2)	-16.62* (2)	-2.28 (2)	-19.52* (2)	0.24* (3)	0.10 (3)
LSC	-3.16 (3)	-15.94* (3)	-4.06 (3)	-19.67* (3)	0.19* (3)	0.14 (3)
HSC	-3.29 (3)	-10.42* (3)	-3.44 (3)	-14.63* (3)	0.36* (3)	0.08 (3)
CPI	5.77 (1)	-7.83* (2)	9.74 (1)	-8.80* (2)	0.16* (3)	0.05 (3)
ELEC	-0.79 (3)	-12.15* (3)	1.86 (2)	-13.23* (2)	0.31* (3)	0.06 (3)
NUCNG	-1.34 (1)	-14.88* (1)	-1.55 (1)	-15.21* (1)	0.21* (3)	0.08 (3)
IPI	4.65 (1)	-11.40* (2)	3.70 (2)	-12.16* (2)	0.26* (3)	0.15 (3)
HCDD	-4.80* (2)	-	-9.82* (2)	-	0.08 (2)	-

ADF: Augmented Dickey-Fuller test. PP: Phillips-Perron test. KPSS: Kwiatkowski–Phillips–Schmidt–Shin. (1): Model without constant or deterministic trend. (2): Model with constant, without deterministic trend. (3): Model with constant and deterministic trend. ADF and PP critical values are taken from MacKinnon (1991). KPSS critical values are sourced from Kwiatkowski, Phillips, Schmidt and Shin (1992). All null hypotheses except KPSS are unit root; while, in KPSS null is stationarity. *: Rejection of the null hypothesis at the 5% significance level.

Table. 5. Zivot-Andrews minimum t-statistics

Series in logarithms	t-statistics	Periods
SO2	-3.53	2004:04
BP	-4.89	2000:01
TC3M	-2.87	2004:05

SO2 t-statistics is estimated from a break in intercept and trend model; whereas BP and TC3M are estimated from a break in intercept only. Critical values are those reported in Zivot and Andrews (1992). Results show no rejection of unit root hypothesis.

5.2. Cointegration analysis

Table 6 summarizes the results of static OLS regression and cointegration analysis (Engle and Granger, 1987) among all variables in order to estimate Eq. (1).

$$SO2_t = C + a_0 DU_t + a_1 AOMCS_t + a_2 LHSC_t + a_3 BP_t + a_4 NUCNG_t + a_5 IPI_t + a_6 TC3M_t + a_7 HCDD_t + \mu_t \quad (1)$$

where C is a constant and DU is a dummy variable taking the value of 1 in 11:2005, 12:2005, 01:2006, and 0 in all other months. This Dummy variable accounts for the dramatically increase in temperatures of the winter season 2005/2006 that obviously affected the electricity consumption and, thus the permit price. ADF and PP tests provide similar evidence to reject the null of zero cointegrating vectors in favour of one cointegrating vector at 5% level. The results show that all the variables are statistically significant into the cointegrating vector. Fig.5 shows that the residual series has stationary trend.

Fig. 5. Actual, Fitted, Residual Graph

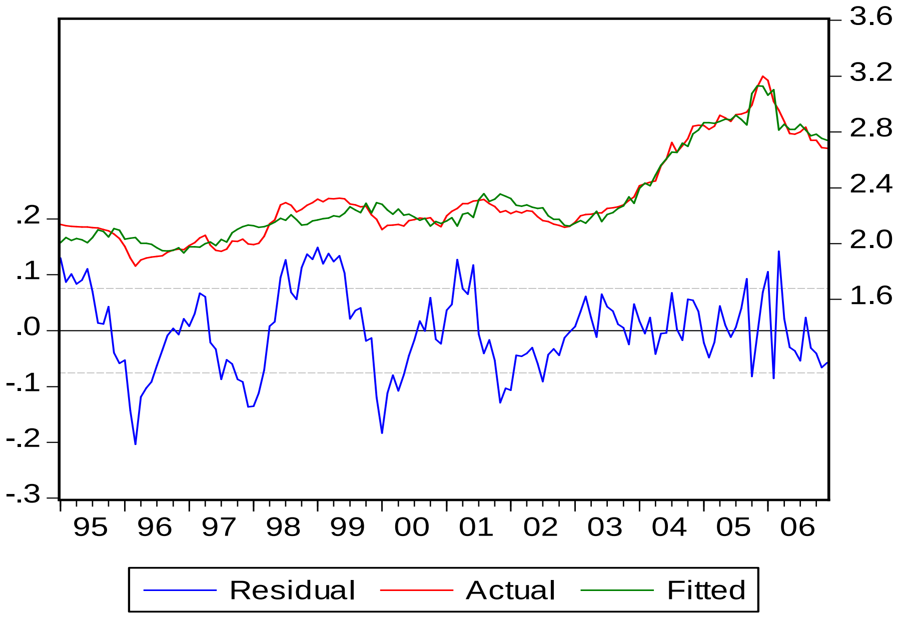


Table. 6. Static Relation

Variables	a_i
C	-5.41***
	[-6.56]
DU	0.28***
	[7.30]
AOMCS	4.25***
	[12.92]
LHSC	-0.65***
	[-4.08]
BP	-0.51***
	[-4.81]
NUCNG	-0.57***
	[-2.98]
IPI	2.25***
	[12.12]
TC3M	0.42***
	[9.48]
HCDD	0.52***
	[2.72]
ADF test statistic	-4.74**
PP test statistic	-4.92**

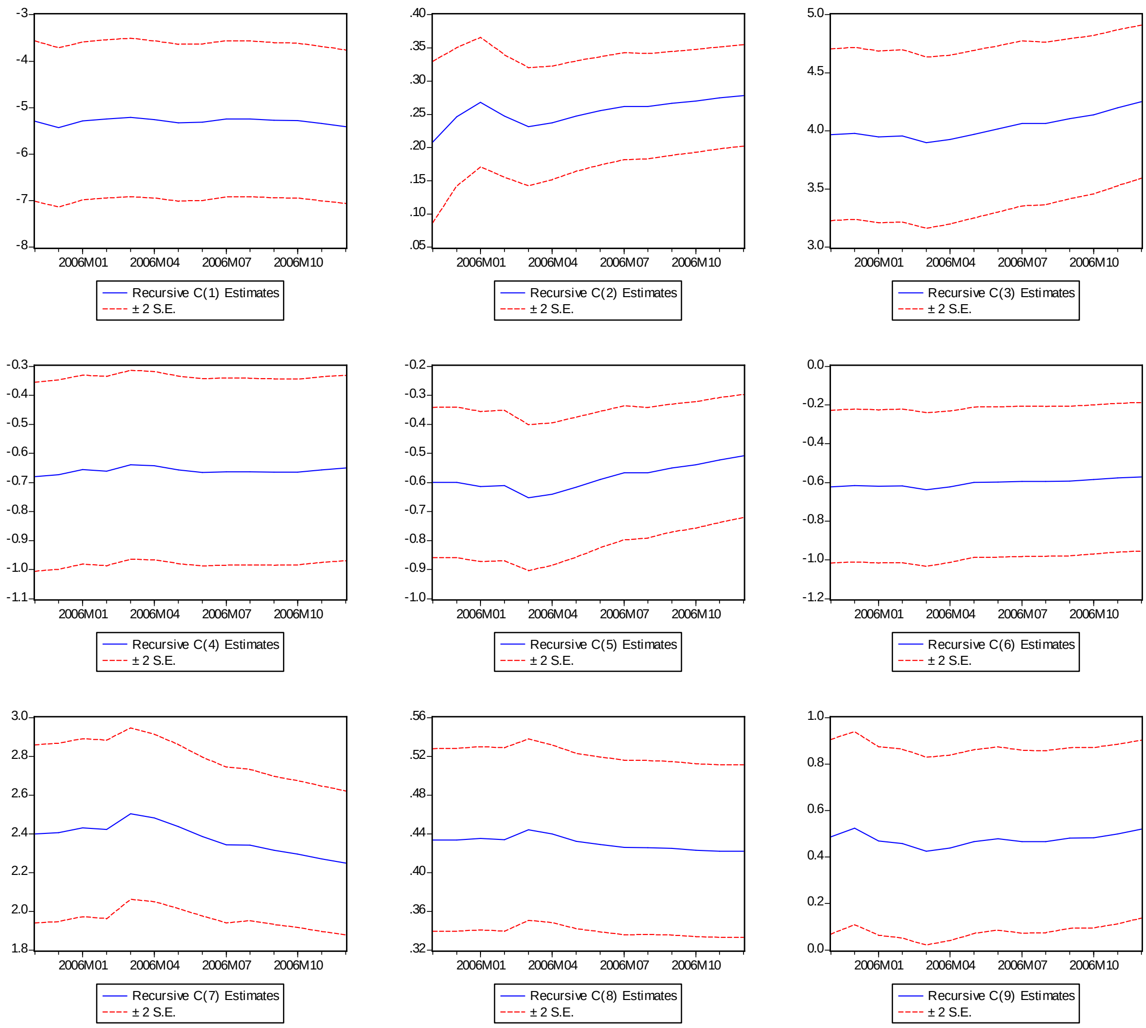
The adjusted R-squared of the static OLS regression is 0.95. The values into brackets are student t-statistics. ** or *** indicate significance at the levels 5% or 1%, respectively.

On the basis of the static relation, we observe first a downward shock in average overhead and maintenance costs of flue gas desulfurization decreases in the long run permit prices. Indeed, a decrease in scrubbing operating costs provides incentives to use scrubbers to control pollution in favour of trading permits, and thus permit prices decrease. This result is comparable to those of Burtraw (1996, 2000), Carlson, Burtraw, Cropper and Palmer (2000), Ellerman, Joskow, Schmalensee and Montero (2000), Popp (2003) and Keohane (2003). Second, an increase in relative low-sulfur prices increases permit prices. Indeed, in the long run, the price effect prevails upon the substitution effect, lowering therefore SO2 prices via the reduction in energy demand. Third, a downward of banked permits increases permit prices. This result confirms the role of banked permits to smooth out the price volatility of permit prices (Godby, Mestelman, Muller and Wetland 1997, Mestelman, Moir and Muller, 1999, Schennach, 2000, and Cason and Gangadharan, 2006). Fourth, an increase of nuclear net generation has a dampening effect on permit prices. This result confirms the theoretical consideration. Indeed, unplanned nuclear plant outages make an increase of power production from coal plants, and as results SO2 emissions increase and SO2 permit prices tend to raise.

Fifth, the coefficient for the industrial production index is positive and is consistent with theory, indicating that an increase in industrial production leads to raise SO2 prices via an increase in SO2 emissions. Sixth, an upward shock in three-month constant maturity rate increases allowance prices. This result is consistent with Schennach (2000) finding, suggesting that the SO2 permit price follow the Hotelling's rule and rise as the rate of interest. Finally, an increase of extreme temperatures, in the long run tends to raise SO2 prices. The sign of the coefficient is as expected positive and as well significant. Indeed, extreme temperatures tend to trigger more energy demand and increase permit prices via emissions increase. This result confirms the appropriateness of including climate variables in the analysis.

We estimate the long-run relationship recursively and test for the stability of the long-run relationship using the recursive estimation. Fig. 6. shows that the recursive coefficients of the sample data remained relatively unchanged during the estimation period.

Fig. 6. Recursive coefficients estimation



5.3. Vector error-correction model

Once the cointegrating relationships have been determined, vector error-correction model (VECM) can be performed. The following table summarizes the results of static OLS regression and the vector error-correction analysis. ECT_{t-1} is the error-correction term, obtained from the cointegration analysis (see table 6). Δ denotes the first difference operator. DU1 is a dummy variable taking the value of 1 in 08:2004 and 0 in all other months. DU2 is a dummy variable taking the value of 1 in 07:2004 and 0 in all other months. These Dummy variables account for the initial uncertainties as EPA finalized the Clean Air Interstate Rule. DU3 is a dummy variable taking the value of 1 in 11:2005 and 0 in all other months. This dummy variable account for dramatically increase in temperatures.

Table. 7. Results of the VECM analysis

Variables	Coefficients
C	-5.88E-05
	[-0.02]
ECT_{t-1}	-0.12***
	[-2.75]
$\Delta SO2_{t-1}$	0.35***
	[4.70]
DU1	-0.15***
	[-4.43]
DU2	0.089***
	[2.61]
DU3	0.11***
	[3.25]
$\Delta AOMCS$	3.01***
	[4.33]
$\Delta TC3M$	0.38***
	[3.56]
ΔCPI_{t-3}	2.18**
	[2.20]
$\Delta HCDD_{t-4}$	0.16**
	[2.42]
ΔLSC_{t-4}	-0.14*
	[-1.72]
ΔNG_{t-6}	-0.11*
	[-1.93]
ΔPET_{t-3}	-0.08**
	[-2.23]
$\Delta ELEC_{t-5}$	-1.70*
	[-1.93]

The adjusted R-squared of the static OLS regression is 0.43. The values into brackets are student t-statistics. *, ** or *** indicate significance at the levels 10%, 5% or 1%, respectively.

The signs of the coefficients are in line with theory. The coefficient in the lagged error correction term measures the speed of adjustment to obtain equilibrium in the event of shock to the system. This coefficient is negative and significant at 1%, implying long-run equilibrium is reached. The coefficient of average overhead and maintenance costs is positive and significant at 1%, which is consistent with previous literature on SO2 permit market (Burtraw1996, 2000; Carlson, Burtraw, Cropper and Palmer, 2000; Ellerman, Joskow, Schmalensee and Montero 2000; Popp, 2003 and Keohane, 2003). The coefficient of the three-month treasury constant maturity rate is positive and significant at 1%, suggesting that SO2 permit price follow the Hotelling's rule and rise as the rate of interest. The coefficient of total monthly degree-days is positive and significant at 5%. Indeed, SO2 permit demand is driven by the degree of climate severity during summer and winter. This result confirms again the appropriateness of including climate variables in the analysis. The coefficients for the low-sulfur coal, petroleum and natural gas prices are negative, indicating that an increase in fuel prices leads to lift electricity production costs, which decreases production and therefore the demand for SO2 permits. An increase in electricity price tends to decrease the demand for electricity and therefore SO2 permit prices. The sign of coefficient for the inflation is positive and significant at 5%. Its positive sign suggests that accelerating inflation conditions contributes obviously to the raise in SO2 permit prices.

The CUSUM and CUSUMSQ stability tests were applied to error-correction model and the graphs representing the tests are presented in Figs. 7 and 8. As can be seen from the following Figs., the plots of CUSUM and CUSUMSQ statistics are well within the critical bounds, implying that all coefficients in the error-correction model are relatively stable.

Fig. 7. Plot of CUSUM

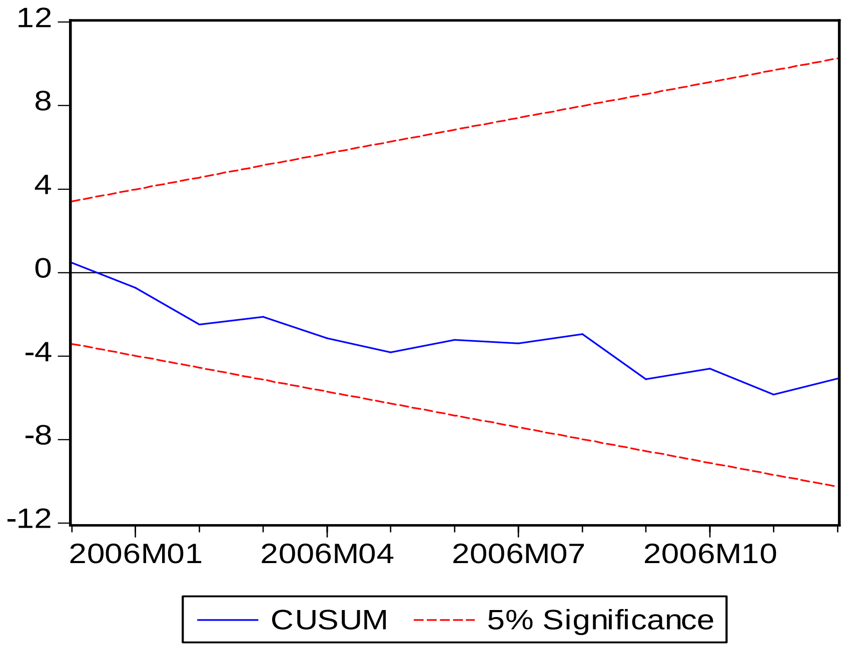
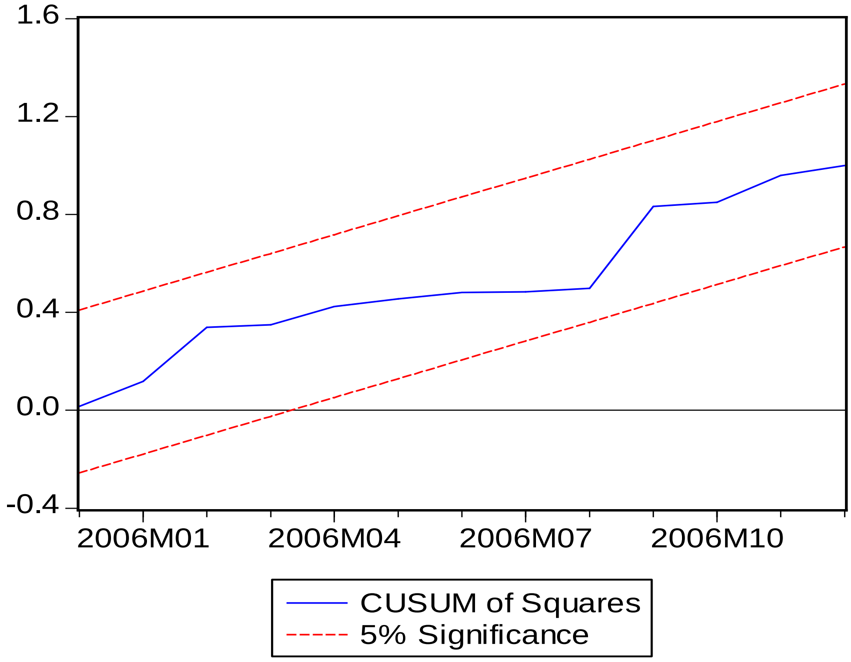


Fig. 8. Plot of CUSUMSQ



6. Conclusion

This paper examined the movement of SO2 permit prices employing monthly data over the period 1995–2006. The approach taken here is quite different from previous studies since weather conditions are taken into account in the estimation procedure. Cointegration techniques were applied to model the relationship between, SO2 permit price, macroeconomic variables, and microeconomic variables in the long- and short-run. The empirical results suggest that in the long-run period SO2 permit price is affected by changes in the three-month treasury constant maturity rate and weather conditions. The stability test performed demonstrates that the SO2 permit price remained relatively unchanged throughout the estimation period. The empirical results using error-correction model estimation suggest that in the short run, SO2 permit price is mostly affected by scrubbing costs, three-month treasury constant maturity rate and weather conditions. The parameter stability of selected vector error-correction model was checked through the CUSUM and CUSUMSQ tests which both indicated the stability. Thus, our econometric model of SO2 prices may be used for forecasting of SO2 prices.

Acknowledgments: We thank Professor Denny Ellerman of Center for Energy and Environmental Policy Research (MIT) for providing SO2 permit price data.

References

Arimura T. H., 2002, "An Empirical Study of the SO2 Allowance Market: Effects of PUC Regulations", *Journal of Environmental Economics and Management*, 44, pp. 271-289.

Arimura T. H., 2003, "Pollution-Permit Market Efficiency: Hedonic Prices of Sulfur in Coal under the U.S. SO2 Allowance Market", *Asahigarasu Zaidan Jyosei Kenkyu Seika Hokoku* (web only).

Bernstein M., Farrell A., and Winebrake J.J., 1994, "The Environment and Economics: the Impact of Restricting the So2 Allowance Market", *Energy Policy*, 22, pp. 748-754.

Bohi, D. R., 1994, "Utilities and State Regulators Are Failing to Take Advantage of Emission Allowance Trading", The *Electricity Journal*, 7, pp. 20-27.

Burtraw D., 1996, "Cost Savings without Allowances Trades? Evaluating the SO2 Emission Trading Program to Date", *Contemporary Economic Policy*, 14, pp. 79-94.

Burtraw D., 2000, "Innovation under the Tradable Sulfur Dioxide Emission Permits Program in the U.S. Electricity sector, Discussion Paper 00-38, Resources For the Futures, Washington.

Carlson C. P., Burtraw D., Cropper M. and Palmer K., 2000, "SO2 Control by Electric Utilities: What are the Gains from Trade?" *Journal of Political Economy*, 108, pp. 1292-1326.

Cason T.N., and Gangadharan L., 2006, "Emissions Variability in Tradable Permit Markets with Imperfect Enforcement and Banking", *Journal of Economic Behaviour and Organization*, 61, pp. 199-216

Chestnut L. G., Mills D. M., 2005, "A Fresh Look at the Benefits and Costs of the US Acid Rain Program", *Journal of Environmental Management*, 77, pp. 252-266.

Chicago Climate Exchange, 2004, "The Sulfur dioxide Emission Allowance Trading Program: Market Architecture, Market Dynamics and Pricing", 2004.

Coggins J. S., Swinton J. R., 1996, "The Price of Pollution: A Dual Approach to Valuing SO2 Allowances", *Journal of Environmental Economics and Management*, 30, pp. 58-72.

Considine T.J., 2000, "The impacts of weather variations on energy demand and carbon emissions", *Resource and Energy Economics*, 22, pp. 295–314

Dickey D.A. and Fuller W.A., 1979, "Distribution of the Estimators for Autoregressive Time Series with a Unit Root", *Journal of the American Statistical Association*, 74, pp. 427-431.

Dickey D.A. and Fuller W.A., 1981, "Likelihood Ration Statistics for Autoregressive Time Series with a Unit Root", *Econometrica*, 49, pp. 1057-1072.

Ellerman A. D., and Montero J. P., 2007, "The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program", Energy Journal, 28, pp. 205-233.

Ellerman A. D., 2003, "Ex Post Evaluation of Tradable Permits: the US SO2 Cap-and-trade Program", MIT Center for Energy and Environmental Policy Research Working Paper 03-003.

Ellerman A. D., Joskow P. L, Schmalensee R., Montero J. P., and Bailey E. M., 2000, "*Markets for Clean Air: The US Acid Rain Program*", New York, Cambridge University Press.

Ellerman A. D., Montero J. P., 1998a, "Explaining Low Sulfur Dioxide Allowance Prices: The Effect of Expectation Errors and Irreversibility", MIT Center for Energy and Environmental Policy Research Working Paper 98-011.

Ellerman A. D., Montero J. P., 1998b, "The Declining Trend in Sulfur Dioxide Emissions: Implications for Allowances Prices", *Journal of Environmental Economics and Management*, 36, pp. 26-45.

Engle R.F., Granger C.W.J., 1987. "Cointegration and Error Correction: Representation, Estimation and Testing", *Econometrica*, 55, 251–276.

Engle R.F., Granger C.W., Rice J. and Weiss A., 1986, “Semiparametric Estimates of the Relation between Weather and Electricity Sales”, Journal of the American Statistical Association, 81, 1986, pp. 310-320.
Fullerton D., McDermott, S.P, and Caulkins J.P, 1997, “Sulfur Dioxide Compliance of a Regulated Utility”, *Journal of Environmental Economics and Management*, 34, pp. 32-53.
Godby R., Mestelman S., Muller R.A. and Welland J. D., 1997, “Emissions Trading with Shares and Coupons when Control of Discharges is Uncertain”, *Journal of Environmental Economics and Management*”, 32, pp. 359-381.
Hahn R. W. and May C. A., 1994, “The Behavior of the Allowance Market: Theory and Evidence”, *The Electricity Journal*, 7, pp. 28-37 (1994).
Helfand G.E., Moore M.R., and Liu Y. (2007), “The Intertemporal Market for Sulfur Dioxide Allowances”, School of Natural Resources and Environment, University of Michigan, November 2007.
International Energy Agency Fuel Research, 1993, “Fuel Specifications - Impact on Power Station Performance”, IEACR/52, London, England.
Joskow P. L., Schmalensee R., Bailey E. M., 1998, “The Market for Sulfur Dioxide Emissions”, *American Economic Review*, 88, pp. 669-685.
Keohane N., 2003, “What did the Market Buy? Cost Savings under the US Tradable Permit Program for Sulfur Dioxide”, Yale Center for Environmental Law and Policy Working Paper.
Keohane, N., 2006, “Cost Savings from Allowance Trading in the 1990 Clean Air Act: Estimates from a Choice-Based Model”, In Jody Freeman and Charles D. Kolstad, eds., Moving to Markets in Environmental Regulations: Lessons from Thirty Years of Experience. New York: Oxford University Press, 2006.
Kosobud R.F., Stokes H.H., Tallarico C.R., and Scott B.L. (2005),”Valuing Tradable Private Rights to Pollute the Public’s Air”, *Review of Accounting and Finance*, 4(1), pp. 50-71.
Kraft J. and Kraft A., 1978, “On the relationship between energy and GNP”, *Journal of Energy and Development*, 3, pp. 401–403.
Kunce M., Hamilton S. and Gerking S., 2005,”Marketable Permits, Low-Sulfur Coal and the Behavior of Railroads”, Mimeo.
Kwiatkowski D., Phillips P.C.B., Schmidt P. and Shin Y., 1992, “Testing the Null Hypothesis of Stationary against the Alternative of a Unit Root. How Sure Are We that Economic Time Series Have a Unit Root?”, *Journal of Econometrics*, 54, pp. 159-178.
Le Compte D.M., Warren HE., 1981, “Modelling the Impact of Summer Temperatures on National Electricity consumption “, Center for environmental Assessment Services, NOAA, Washington, DC 20235.
Lile R. and Burtraw D., 1998, “State Level Policies and Regulatory Guidance for Compliance in the Early Years of the SO2 Emission Allowance Trading Program”, Resources For the Future Discussion Paper 98-35.
MacKinnon J.G., 1991, “Critical Values for Cointegration Tests”, in Engle R.F. and Granger C.W.J. (eds), *Long-run Economic Relationships*, Oxford University Press, pp. 267-276.
Mestelman S., Moir R. and Muller R. A., 1999, “A Laboratory Test of a Canadian Proposal for an Emissions Trading Program”, in *Research in Experimental Economics*, vol. 7, C. Holt and R. M. Isaac (eds.), Stamford, Conn.: JAI Press, pp. 45-92.
Mizobuchi K., 2004, “The Movements of PUC Regulation Effects in the SO2 Emission Allowance Market”, Kobe University, Graduate School of Economics.
Peirson J. and Henley A., 1994, “Electricity Load and Temperature: Issues in dynamic specification”, *Energy Economics*, 16, pp. 235-243.
Perron P., 1989, “The Great Crash, the oil price shock and the unit root hypothesis”, *Econometrica*, 57, pp.1361–1401.

Phillips P.C.B and Perron P., 1988, "Testing for a Unit Root in a Time Series Regression", *Biometrica*, 75, pp. 335-346.
Popp D., 2003, "Pollution Control Innovations and the Clean Air Act of 1990", *Journal of Policy Analysis and Management*, 22, pp. 641-660.
Rose K., 1997, "Implementing an Emissions Trading Program in an Economically Industry: Lessons from the SO2 Trading Program". In '*Market-Based Approaches to Environmental Policy: Regulatory Innovations to the Fore*' (ed.) R. Kosobud and J. Zimmerman, New York, Van Nostrand Reinhold.
Rose K, Taylor AS, Harunuzzaman M., 1993, "Regulatory treatment of electric utility compliance strategies, costs and emission allowances", The National Regulatory Research Institute, Ohio State University.
Schennach S.M., 2000, "The Economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments", *Journal of Environmental Economics and Management*, pp. 189-210.
Slade M.E., and Thille H., 1997, "Hotelling Confronts CAPM: A Test of the Theory of Exhaustible Resources", *Canadian Journal of Economics*, 30(3), pp. 685-708.
Sotkiewicz P. M., Holt L., 2005, "Public Utility Commission Regulation and Cost-Effectiveness of Title IV: Lessons for CAIR", *The Electricity Journal*, 18, pp. 68-80.
Sotkiewicz P. M., 2002, "The Impact of State-Level Public Utility Commission Regulation on Compliance Costs Associated with the Market for SO2 Allowances", University of Florida, Public Utility Research Center.
U.S. Environmental Protection Agency (USEPA), 1995-2006, '*Acid Rain Program Progress Reports*', http://www.epa.gov/progress/
U.S. Energy Information Administration, 1994, "Electric Utility Phase I Acid Rain Compliance Strategies for the Clean Air Act Amendments of 1990." DOE/EIA-0582, 1994, Washington, DC.
U.S. Energy Information Administration (EIA), "Electric Power Monthly Reports', 1994-2006, http://www.eia.doe.gov/cneaf/electricity/epm/matrix96_2000.html
Winebrake J. J., Farrell A. E., Bernstein M. A., 1995, "The Clean Air Act's Sulfur Dioxide Emissions Market: Estimating the Costs of Regulatory and Legislative Intervention", *Resource and Energy Economics*, 17, pp. 239-260.
Zivot E. and Andrews D.W.K., 1992, "Further evidence on the Great Crash, the oil price shock and the unit root hypothesis", *Journal of Business and Economic Statistics*, 10, pp.251–270.