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Market Efficiency and the U.S. Market for Sulfur Dioxide Allowances

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Abstract

Focusing on the U.S. sulfur dioxide (SO_2) allowance market from its inception (in 1994) to 2009, we model allowance prices to determine the influence of market fundamentals—such as prices of high- and low-sulfur coal—on allowance price level and volatility. Our empirical analysis finds that the SO_2 market, similar to other emission markets studied in the literature, had relatively weak influence of market fundamentals for several years after launch—that is, allowance prices did not reflect marginal abatement costs for the first several years of operation. However, we find evidence of increased influence of market fundamentals after the first few years of the program but before a court decision that introduced significant uncertainty into the market in mid-2008. We also find that market volatility increased in response to all types of communications from the administrator, suggesting that the development of a formal communication strategy, possibly similar to the strategy used by central banks, would reduce price volatility and increase the efficiency of the market.

Keywords: Sulfur dioxide market, cost-effective, efficiency, volatility, communication policy

1. Introduction

Economists generally concur that market-based approaches are a more cost-effective approach for reducing pollution in certain sectors than command-and-control regulation (see, for example, Baumol and Oates, 1988; CBO, 2009). That conclusion rests on the assumption that a market-based approach will constantly coordinate the behavior of relevant parties through prices in the market created to reduce pollution. The price could be determined endogenously by the market or could be set exogenously as a tax rate on pollution. Either way, the marginal cost to reduce pollution will be equated across all market participants and, if allowed under the approach, across time. However, if the market produces prices (for example, in a cap-and-trade program) that do not represent the marginal cost of pollution reduction, the cost-effectiveness argument in favor of market-based approaches may no longer be accurate.

This paper uses the United States Environmental Protection Agency's (EPA's) Acid Rain Program to evaluate the validity of the assumption that prices in the cap-and-trade program have responded to changes in the marginal cost of reducing sulfur dioxide (SO_2) emissions over the first 15 years of the program. The Acid Rain Program was enacted in 1994 with the goal of reducing annual SO_2 emissions by 45 percent compared with 1980 levels. Allowances to emit SO_2 were mostly given for free to electricity-generating units, although a small portion of allowances was sold in annual auctions.[1] After the allowances were distributed, they could be traded in a secondary market by regulated firms and by any other participants that registered with the EPA. Firms subject to the caps—primarily coal-burning electricity generators—were required to submit allowances to the EPA each year; however, allowances not used for compliance in a particular year could be shifted from one year to another by "banking" them.

The price of SO_2 allowances changes frequently as buyers and sellers assess new information about the cost of reducing emissions, the demand for electricity, and changes in the regulations governing the program (see Figure 1). The changing allowance price leads regulated firms to seek the least expensive combination of cuts in SO_2 emissions and purchases of allowances to comply with the cap, thus guiding the economy toward the lowest-cost approach for reducing SO_2 emissions to the level of the cap. However, the validity of that outcome depends on whether allowance prices are determined by market fundamentals (for example, electricity usage or the price of high-sulfur and low-sulfur fuels that produce electricity). If they deviate from fundamentals because, for example, the market is too thinly traded, a more efficient market could allow the economy to meet the cap for a lower cost. That is, if allowance prices are higher than supported by fundamentals, the economy would be using too few allowances in the current period and abating more than necessary, causing the price of electricity to be higher than it would be in an efficient market.

This study develops a model to analyze the efficiency of the SO_2 market by determining whether market fundamentals predominantly explain allowance prices. In contrast, the study does not evaluate the social efficiency of the level of the cap or the degree to which marginal social costs

[1] Selling all of the allowances in an auction would have increased budget receipts but might also have increased opposition to the program from firms that otherwise would have received the allowances for free. Neither approach, however, would be expected to affect the value of the allowances in the secondary market.

and marginal social benefits are equated. Our approach is similar to one used to study the European Union Emissions Trading System (EU ETS)—a cap-and-trade program for greenhouse gas (GHG) emissions in Europe (Hintermann, 2010). The EU ETS operates as the U.S. SO_2 cap-and-trade program does, with the exception that GHG allowances could not be banked between the first and second phases of the EU ETS. (The SO_2 cap-and-trade program also contained multiple phases, but allowances were bankable across phases.) Hintermann found that allowance prices did not reflect fundamentals in the first phase of the EU ETS, but did track much closer to fundamentals in the second phase. That result suggests that the EU ETS cap-and-trade program was not operating efficiently for the first several years of the program.

Although there are many detailed analyses about various aspects of the SO_2 cap-and-trade program (for example, Joskow et al., 1998; Stavins, 1998; Burtraw et al., 2005; Burtraw and Szambelan, 2010; Chan et al., 2012), no studies have considered the direct role of market fundamentals in determining allowance prices over the full history of the program. However, studies have used other approaches to analyze the efficiency of the SO_2 program, and often for shorter periods of time: Ellerman and Montero (2007) found the market to be efficient because actual and theoretically predicted banking behavior were very similar. Conversely, Helfand et al. (2006) found that the monthly SO_2 price path could have allowed for intertemporal arbitrage, suggesting some inefficiency in the market, caused, in part, by a structural break in the program. Carlson et al. (2000) concluded that although the program generated cost savings, some additional cost savings should have been realized under an efficient trading scheme during the first two years of the program; the authors did not test for efficiency in subsequent years of the program. And Parsons et al. (2009) analyzed periods of high volatility to conclude that illiquidity in the market contributed to some inefficiency between 2005 and 2008.

Our analysis uses monthly and daily spot prices for SO_2 allowances dating back to the start of the trading program.[2] Using a model to link those prices with variables that would be expected to affect the marginal cost of SO_2 reductions, we find that allowance prices are explained by market fundamentals after the first four years of the program; during those first four years, non-fundamental variables such as allowance prices in the previous period have the most predictive power in describing the movement in allowance prices. We also find a structural break in the data—following a court decision that would itself be considered a market fundamental and that introduced significant uncertainty into the future of the Acid Rain Program. After that decision, market fundamentals continue to play a role, but of a lesser magnitude than before the break. That result supports the belief by economists that market-based approaches—in particular, the SO_2 trading program in the United States—can operate cost-effectively to reduce pollution, but

[2] Trading of SO_2 allowances is largely done in private bilateral negotiations between two parties (i.e., over the counter) and not on centralized, transparent exchanges. For that reason, spot price data for SO_2 allowances tend to be proprietary and difficult to obtain. One of the few firms that maintained historical records of SO_2 spot price allowance data (Cantor Fitzgerald) suffered a tragic loss of employees working in its World Trade Center offices on September 11, 2001. At that same time, daily spot price transactions for SO_2 allowances were also lost; however, monthly prices remain that go back to the launch of the program.

that the first few years of operation may benefit from additional education and support of participants.[3]

A second contribution of the paper is to extend the research on optimal communication policy of central banks to the communication strategy of regulators of environmental emissions markets. Just as central banks have significant control over actions that could affect inflation or interest rates, regulators of environmental markets have significant control over some factors that affect the price of allowances. For example, regulators can change the allowances cap, the number of regulated firms, or the firms' ability to bank allowances, all of which would be expected to affect allowance prices. With respect to central banks, Janet Yellen, Vice Chair of the Board of Governors of the Federal Reserve System, stated in November 2012, "A growing body of research and experience demonstrates that clear communication is itself a vital tool for increasing the efficacy and reliability of monetary policy" (Yellen, 2012). We are not aware of other analyses that similarly highlight the importance of establishing best practices for communication policy in environmental markets.

A recent review of the communication policies of central banks describes the objective as generally to increase the quality of the content signals and reduce noise (Blinder et al., 2008). A high content-to-noise ratio might also introduce volatility in market prices, but that volatility is induced by new information about the market and is generally considered a desirable feature of any market. Conversely, volatility connected to noise—for example, inconsistent explanations of potential changes by many individuals, or a retraction of a previous policy statement—is not a desirable feature of the market.[4] There is a significant body of research devoted to the detrimental effects of price volatility, or uncertainty, on the irreversible investment decisions of firms (Pindyck, 1991; Guthrie, 2006; Fuss et al., 2008; Fuss et al., 2010). In environmental markets, reduced investment in new technologies—technologies that would otherwise lower the marginal cost of pollution reductions—could reduce the cost-effectiveness of the market.[5]

Empirical research of the effect of policy uncertainty on investment and economic growth in markets has found significant downward effects of uncertainty on real GDP, private investment, and aggregate employment (Baker, Bloom, and Davis, 2013). In an environmental context, research has found greater investment risk resulting from policy uncertainty related to the development of a climate market in the United States (Blyth et al., 2007; Yang et al., 2008).

[3] That result buttresses the assumptions underlying other market-based programs, such as a renewable fuel standard, a renewable electricity standard, and water-quality trading programs.

[4] Blinder (2004) describes the "cacophony problem" as a situation in which too many different explanations of a policy position might confuse rather than elucidate the policy—for example, when each member of a committee offers an explanation. Issing (2005) describes a situation in which previously announced policies do not materialize and thus damage the credibility and perceived signal-to-noise value of future announcements.

[5] The introduction of volatility from a rule change may be necessary if the market administrators or another oversight entity determines that the rules should be changed to reflect new information. However, frequent changes in the rules, even if warranted by better information, would be expected to increase uncertainty in the future program rules and reduce investment, which could increase the cost of the program.

The objective of a communication policy is to ensure that, when important market-moving announcements are made, all market participants are notified at the same time with clear information about the actions taken by the administering entity. Requiring market participants to check the administrator's website continually for updates or to rely on press coverage of announcements creates opportunities for some participants to learn and trade on new information before others. Acknowledging that possibility in other markets, some federal agencies such as the Federal Reserve and the Bureau of Labor Statistics have implemented communication policies intended to limit the ability for some participants to learn news early, which reduces volatility in the market.[6] Recent research has evaluated some of the implications of how EPA makes announcements and has concluded that changes to its current practice could better serve the objectives of the agency (Muehlenbachs et al., 2011)

Following standard methodology in the central bank communication literature, we construct a variable that describes two types of announcements to the Acid Rain Program over the first 15 years of its operation: those that represent permanent structural changes to the program and those that represent administrative decisions, or decisions where the regulator has some flexibility regarding day-to-day implementation or elected officials indicate an intention to make changes.[7] To the extent that both types of announcements contain information that fundamentally alters the value of an allowance, they would be considered market fundamentals and thus would be of interest to all market participants. We find that both types of announcements about regulatory changes significantly increase volatility. The relative magnitude of the volatility associated with permanent announcements compared with the volatility associated with administrative announcements is consistent with the effect of policy announcements on volatility found in the central banking literature (Kohn and Sack, 2004).

The fact that both types of program announcements increased the volatility of allowance prices suggests that market participants are monitoring communications from EPA and other governing bodies for market-moving information. Communication policies are designed to release new information in an organized, transparent, and predictable method by strengthening the signal and reducing the likelihood that some participants miss announcements, misunderstand announcements, or learn about them after others. Because communication policies reduce uncertainty in the market and because uncertainty breeds volatility, which can reduce the cost-effectiveness of the market, administrators of environmental markets could improve market efficiency by considering implementation of announcement policies, perhaps similar to those adopted by central banks and other market-moving agencies. Such policies might be especially relevant now because several U.S. states (e.g., California, Washington, and New Mexico) and

[6] The announcement policy of both organizations is frequently updated to reduce the potential for information leakage that could provide an opportunity for some traders to make money on the forthcoming announcement or cause the market to extract signals about the leaked information from imprecise sources. See Carpenter (2004) and Blinder et al. (2008) for a review. As a recent example, see Javers (2013).

[7] Kohn and Sack (2004) identify announcements as prescheduled communications, which include announcements of policy decisions, or as irregular statements, which may include speeches or interviews. Our analysis also follows on a large literature on the effect of announcements on the stock and bond market (see, for example, Ederington and Lee, 1993; Fleming and Remolona. 1997; and Bomfim, 2003).

countries (e.g., New Zealand, Canada, and Australia) are designing and launching cap-and-trade programs to curb GHG emissions.

2. Allowance Trading Under the Acid Rain Program

The Acid Rain Program was enacted on November 15, 1990, under Title IV of the Clean Air Act Amendments.[8] The program was implemented in two phases.

- Phase I (1995 to 1999) covered 445 electricity generating units (EGUs): 263 EGUs that were required to participate, and an additional 182 that voluntarily opted into the program.[9] The EPA issued allowances between 1995 and 1999 that represented a 20 percent reduction in emissions of the regulated entities in 1999 compared with 1990 emissions and a 29 percent reduction in emissions in 1999 compared with 1980.
- Phase II (2000 to the present) affects all existing and new generating units with a capacity of more than 25 megawatts: 3,391 units in 2004 and 3,572 units by 2009 (EPA, 2010). In 2000, the EPA issued allowances representing a 40 percent reduction in emissions compared with 1990 and a 45 percent reduction compared with 1980.

Figure 2 shows a map of regulated EGUs, and Figure 3 shows emissions and caps for the program in Phases I and II.

Based on historical emissions, allowances were allocated to some regulated entities free of charge. In Phase I, the EPA allocated allowances to each entity at fixed ratio of 2.5 pounds of SO_2 per million British thermal units (mmBTU) of energy in the fossil fuels consumed by those entities on average between 1985 and 1987 (EPA, 2009b). In Phase II, that ratio was reduced by 50 percent. So, in the first year of the program, in anticipation of that reduction in free allocation, regulated entities started banking allowances for future use. The bank of allowances grew until 2000, when it stood at 11.6 million allowances (EPA, 2010). It fell to 6 million allowances by 2006 and then started to rise again to 8.6 million allowances by 2009 (see Figure 4).

In addition to the free allocation, a small number of allowances were auctioned in public auctions (150,000 per year between 1995 and 1999; 125,000 in 2000 and thereafter). The auction design is a discriminatory-priced sealed-bid auction, such that each winning bidder pays their bid. Such an auction is not noted for providing an efficient mechanism for price discovery, because it creates incentives for participants to submit bids that deviate from the value of the good being sold (Cason, 1993; Swinkels, 1999).[10]

After allowances were distributed, allowance holders were able to trade them with other approved allowance holders. The EPA reported that "early [SO_2 allowance] trades required considerable legal advice, cost as much as $5 per ton in brokerage fees, and took months to

[8] The Clean Air Act Amendments of 1990; Public Law 101-549.

[9] The voluntary opt-in program existed in Phase I to allow units regulated under Phase II to opt into the program early. By opting in, a unit received allowances equal to its emissions in a specified base year. The opt-in program is believed to have lowered costs for Phase I mandatory units, and also to have attracted units that had already lowered emissions relative to their base years. As a result, many opt-in units received excess allowances that they could sell for additional profits (Montero, 1999; EPA 2009a).

[10] Other environmental markets have adopted a more efficient auction design; the Regional Greenhouse Gas Initiative and most of the EU country-specific auctions for carbon GHG allowances use a sealed-bid uniform-price option, in which the clearing price is determined by the highest rejected bid.

complete” (EPA, 2004). By 2004, those fees were estimated to have dropped to $0.50 per ton and could be executed in one to two weeks (see Figure 1 for a history of allowance prices). In 2004, 15.3 million allowances were traded between entities; 49 percent of those trades were between distinct entities, and the remaining trades were, for example, transactions between two facilities within a given firm (EPA, 2010). In addition to the spot market for allowances, there was an active market for allowance derivatives estimated at the same size as the spot market (CBO, 2010).

At the conclusion of each compliance year, firms were required to surrender the number of allowances equal to their emissions, based on measurements from their continuous emission-monitoring systems. Firms that could not produce the required allowances paid a penalty of $2,000 per ton of emissions in excess of the allowances produced (or more than five times the average cost of allowances during the first decade of the program); the penalty was annually adjusted for inflation from a 1990$ base. Between 1995 and 2010 there were 76 cases of non-compliance, with regulated utilities paying compliance on about 1500 allowances.[11]

Price Movements between 2003 and 2008. In December 2005, SO_2 allowances traded for more than $1,600 per ton (in 2000$) compared with an average of $147 per ton for the previous 10 years of the program. Multiple factors contributed to that dramatic price increase; the most significant factors are thought to be an EPA rule and a piece of legislation proposed in 2003 and 2004 that would have effectively tightened the SO_2 cap. The first was the EPA’s Clean Air Interstate Rule (CAIR), proposed in December 2003, which targeted emissions of SO_2 and atmospheric nitrogen oxides (NO_x) in 28 Eastern states and the District of Columbia. Although the universe of regulated entities would be similar to those in the Acid Rain Program, CAIR aimed to reduce SO_2 emissions by an additional 50 percent in 2010 and an additional 60 percent by 2015. It was proposed that the program would be implemented by reducing the value of allowances in 2010 to half their value before 2010; an allowance in 2010 would offset 0.5 tons of emissions instead of 1 ton of emissions. The second potentially large reform was the Clear Skies Act, which was introduced in 2002 and gained traction in 2003. It would have cut emissions in 2010 by 50 percent by issuing half as many allowances as before 2010. The rule and the proposed legislation contributed to the large increase in allowance prices that began in 2004.

A second important factor contributing to the price increases was a series of disruptions within the commodity markets that supplied regulated entities with SO_2 abatement options. First, multiple railroad track failures and mine outages led to an increase in the price of low-sulfur coal in the fall of 2005 (Parsons et al., 2009). In addition, when Hurricanes Katrina and Rita struck the United States in August and September 2005, they disrupted production of natural gas, a low-sulfur approach to generating electricity (Barnett and LaCount, 2005). Both events increased the effective cost of compliance and thus put upward pressure on allowance prices starting in late 2005. At the time of the spike, the market had banked 6.8 million allowances from one year to the next, representing more than 65 percent of the number of allowances retired in 2005 (see Figure 4). In theory, that bank of SO_2 allowances could have tempered any price spikes, because it could be drawn down at any time. However, that did not occur to a large enough degree to temper the increase in prices.

[11] Based on data available from EPA (2013).

A third reason credited for the price spike relates to illiquidity in the market. Liquidity is the ease with which market participants can buy or sell at the current market price. In a liquid market, investors can quickly buy or sell large quantities of an asset without affecting its price; in contrast, buyers in an illiquid market can affect prices. During the 2005 price increase, the top 10 most active buyers accounted for 48 percent of trading volume, compared with 26 percent for the previous 10 years. The top 10 sellers during that period accounted for 44 percent of volume, compared with 24 percent over the previous 10 years.

Liquidity in a relatively open market such as the SO_2 market is often assumed to be provided by traders and other speculators who stand ready to serve as the counterparty to those wanting to buy or sell. As stated earlier, however, regulated entities were freely allocated 95 percent of allowances, and the vast majority of subsequent trading occurred over the counter. Without the price transparency and clearing services offered by an active exchange, it could have been expensive for firms to locate a counterparty or to determine whether a broker who offered to trade with them was offering a fair price. Moreover, many of the entities regulated under the Acid Rain Program were also regulated in the electricity market by a public utility commission or another regulator that approved the electricity rate the regulated entities were allowed to pass on to consumers. In many cases, those regulated utilities were prohibited from accruing trading profits in the market (which could then be distributed to shareholders and employees) because of cost-of-service regulation, which stipulates that all profits must be passed on to electricity consumers (Barnett and LaCount, 2006). Complementing that reduced incentive to earn a profit were the steep fines associated with not having sufficient allowances at compliance time. Those factors, combined with the lack of trading transparency, provided regulated entities with little incentive to trade, even when allowance prices were 10 times larger than in the previous year.

3. Market Fundamentals in the Acid Rain Program

To motivate an analysis of efficiency in the market, we start with a small representative producer of electricity that has a portfolio of coal, natural gas, and renewable generating plants and an objective of minimizing generation costs while producing a sufficient amount of electricity to satisfy exogenously determined demand ($\bar{E}$):

$$\begin{aligned} &\min_{E_{LSC},E_{HSC},E_{NG}} p_a\left[\delta_1\left(E_{LSC}\right)+\delta_2\left(E_{HSC}\right)+\delta_3\left(E_{NG}\right)\right]+C_1\left(E_{LSC}\right)+C_2\left(E_{HSC}\right)+C_3\left(E_{NG}\right)+C_4\left(E_R\right) \\ &s.t.\ \ \bar{E}=E_{LSC}+E_{HSC}+E_{NG}+E_R \end{aligned} \quad (1)$$

where the subscripts on the electricity variable (E) represent low-sulfur coal (LSC), high-sulfur coal (HSC), natural gas (NG), and renewables (R); p_a is the endogenous price of allowances; $C\left(E_i\right)$ is the cost of producing electricity from each source of energy i ($C'>0, C''>0$) and incorporates any abatement costs associated with that source; and the function δ_i describes the production of SO_2 when generating electricity from fuel source i ($\delta'>0$) where renewable sources do not produce SO_2. The first order conditions are:

$$\lambda = p_a\delta_1'\left(E_{LSC}\right)+C_1'(E_{LSC}) = p_a\delta_2'\left(E_{HSC}\right)+C_2'(E_{HSC}) = p_a\delta_3'\left(E_{NG}\right)+C_3'(E_{NG}) = C_4'(E_R) \quad (2)$$

where λ is the Lagrangian multiplier on the electricity production constraint and can be interpreted as the marginal cost of increased production. In equilibrium, the marginal cost of production from any source of energy should be equal. If the price of HSC increases, more electricity will be produced from the other three sources, all of which emit less sulfur when consumed than HSC emits. Thus, the price of allowances would be expected to fall. Alternatively, if there is an increase in the total demand for electricity (rising λ), then more consumption of all fuel sources would be required, and the allowance price would be expected to rise.

If the market is efficient, market fundamentals include the marginal cost of the fuels (high-sulfur and low-sulfur coal, natural gas, and renewables) used to generate electricity, each fuel's marginal release of sulfur when used to generate electricity, the demand for electricity, and any available information about the future structure and rules associated with the Acid Rain Program that might affect the supply of allowances or the cost of emission reductions.

Emission Reduction

Regulated entities can reduce their emissions in several ways: 1) by installing air scrubbers that remove SO_2 from the smokestack prior to emission into the atmosphere; 2) by shifting from high-sulfur coal to low-sulfur coal to generate electricity; 3) by switching from coal to natural gas to generate electricity; or 4) by shifting from coal to a renewable electricity source such as hydropower, a sulfur-free approach for generating electricity.

The installation of a scrubber is a much more capital-intensive option than the fuel-switching options, although the ongoing maintenance costs of a scrubber are low. That long-run decision would change the cost function for using each fossil fuel and would also change the form of δ_i, which describes the production of SO_2 from generating units. Regulated entities require a degree of policy certainty to justify the large capital investment represented by a scrubber. Thus, both policy uncertainty and higher capital costs could have a negative effect on scrubber installation and would be expected to raise the cost of allowances. However, because the price of scrubber installation is available only on an annual basis, without much change over the time period analyzed, it is not included as a market fundamental in this analysis.

Low-SulfurCoal. The SO_2 emissions from coal-fired power plants depend on the sulfur content of the coal used as a fuel source. Bituminous coal from the Appalachian region has a higher sulfur content but also a higher heat content than sub-bituminous coal found in the Powder River Basin in Wyoming. Despite the lower heat content, Powder River Basin coal tends to be more expensive than Appalachian coal because of the cost of transporting it from Wyoming to the coal-fired power plants, which primarily exist in the East and Southeast United States. To comply with the Acid Rain Program, regulated coal-fired power plants can substitute high-sulfur Appalachian coal in exchange for low-sulfur Powder River Basin coal to reduce SO_2 emissions. Substitutions of 20 percent to 30 percent can occur with minimal plant modifications, whereas a wholesale switch from Appalachian coal to Powder River Basin coal can require a more expensive retrofit of the plant to respond to the different properties of the low-sulfur coal. An unexpected increase in the price of low-sulfur coal would be expected to cause allowance prices to increase.

Natural Gas. The use of natural gas to generate electricity produces much less SO_2 than coal produces, regardless the source of coal; thus, increased reliance on natural gas is another abatement approach for electric utilities. That occurs primarily by shifting electricity generation from a coal-fired plant to a natural gas plant or, to a lesser extent, by substituting natural gas for coal within a given plant. In 2009, approximately 1 percent of electricity was produced from a facility that used both natural gas and coal in the same burner (Energy Information Administration, 2009). An unexpected increase in the price of natural gas would make switching from coal to natural gas more expensive and would require more allowances for compliance.

Hydropower. Hydropower accounts for 7 percent to 9 percent of electricity generation in the United States. Those states with the most hydropower (Washington, Oregon, and California) have relatively few coal-fired generators. The availability of hydropower influences the demand for electricity from coal and natural gas and thus the demand for allowances. During unexpectedly dry summers, the lack of availability of hydropower means that coal plants would be expected to operate for longer periods, leading to an increase in the demand for SO_2 allowances.

Demand for Emission-Intensive Goods and Services

The equilibrium price of allowances would be expected to reflect anticipated changes in the demand for electricity. There are three primary sources of unexpected changes in the demand for electricity: 1) an uncharacteristically hot summer would increase the use of air conditioning, which is almost exclusively electric-powered; 2) an uncharacteristically cold winter would increase the need for heating, which is fueled by utilities delivering either natural gas or electricity; and 3) increased economic activity would be expected to correlate with increased use of electricity. To the extent that generation of that electricity is fueled by coal, an unanticipated hot summer or cold winter would be expected to increase the demand for SO_2 allowances.[12] The second effect of cold winters on allowance prices is an increased demand for natural gas, which is a substitute for coal. The increased demand for natural gas would be expected to cause natural gas prices to increase and thus to reduce its use as a low-sulfur alternative to coal. That increase in natural gas prices would also be expected to cause electricity generators to increase demand for SO_2 allowances. Finally, unanticipated economic growth would be expected to correlate with increased demand for electricity and thus with increased demand for allowances (see, for example, Soytas and Sari, 2003).

Regulatory Policy Announcements

Periodic regulatory announcements are expected in a program such as the Acid Rain Program because, for example, economic conditions change or because new information becomes available about the health effects or costs of regulated pollutants. If those announcements affect the supply of allowances, then the associated changes would affect the cost of allowances in a cap-and-trade program. In an efficient market, however, only unanticipated policy announcements would be expected to have an impact on allowance prices. That effect contrasts with the effect of anticipated policy announcements such as the commencement of Phase II, which lowered the annual cap and reduced allocations to regulated entities. Because regulated entities knew that that change was coming, they banked allowances and, as a result, the market price did not jump when Phase II launched.

[12] In 2007, 33 percent of homes used electricity for heating and 57 percent used natural gas for heating (EIA, 2010).

In contrast, as an example of a policy announcement that was not anticipated far in advance, the Clinton Administration announced in March 1997 that it would tighten the National Ambient Air Quality Standards (NAAQS) for fine particulates. Many electric utilities responded to the new particulate standard by switching from coal to natural gas, which reduced particulate emissions. That switch to natural gas produced a co-benefit of also reducing SO_2 emissions, which had the same effect on SO_2 allowance prices as did loosening the SO_2 cap (that is, the new rule lowered baseline emissions, which made the existing cap less stringent). Consequently, the reduced demand for SO_2 allowances caused allowance prices to drop.

Any regulatory change that affects market fundamentals would probably cause allowance prices to become more volatile, which could cause regulated entities to delay investment in abatement technologies until any uncertainty associated with the announcement has been settled. To the extent that regulatory changes are frequent, contain incomplete information, or are later reversed, regulated entities may forgo capital investments for an extended period of time until the policy uncertainty has been resolved. For example, increased regulatory uncertainty may cause electric utilities regulated under the Acid Rain Program to opt for fuel-switching abatement options instead of installing more capital-intensive scrubbers or converting coal-fired generators to burn a higher fraction of low-sulfur Powder River Basin coal. As that example shows, regulatory uncertainty can, as a consequence, increase the cost of market-based programs, offsetting some or all of the social benefits that would presumably be created by a policy change.

4. Econometric Model

The econometric analysis brings data to the above model to evaluate the efficiency of the allowance market established by the Acid Rain Program. We analyze efficiency in two ways: 1) the extent to which market fundamentals, as described above, are a determinant in establishing SO_2 allowance prices and 2) the roles that different types of regulatory announcements play in affecting price volatility in the allowance market.

Market Fundamentals

An efficient allowance market would be characterized by allowance prices that reflect current information underlying supply and demand for allowances. Thus, traders should not be able to consistently achieve profits from trading allowances, because all known information is already present in prices. Prices in an efficient market would be expected to exhibit the Markov property—that current prices are the best predictor of future prices and that past prices provide no useful information about future prices. If that were not the case, traders could arbitrage the market by following trends in allowance prices—buying allowances when prices start to move up and selling allowances when prices start to move down. However, in practice, asymmetric information, risk aversion, fixed contracts, and bounded rationality are all reasons why allowances might not have the Markov property and might therefore depend on past prices.

One way to test for the role of market fundamentals in determining allowance prices is to regress allowance prices on market fundamentals and lagged price changes. If changes in the allowance price are explained primarily by market fundamentals, then that explanation supports an efficiency claim for the SO_2 market. Conversely, if introducing the lagged allowance price improves the explanatory power of the model, then the allowance market is thought to be less efficient and to be inconsistent with economists' predictions.[13]

The baseline econometric model (Model 1) is given by equation (3).

$$\Delta SO2_t = \beta_0 + \beta_1 \Delta Natural\,Gas_t + \beta_2 \Delta Coal\,Low\,Sulfur_t + \beta_3 \Delta Coal\,PA_t + \beta_4 \Delta Load_t + \beta_5 \Delta Drought\,Index_t + \beta_6 \Delta Rail\,Freight\,Costs_t + \Gamma Policy_t + \Delta \epsilon_t \quad (3)$$

In Model 1, the change in log SO_2 allowance prices ($\Delta SO2_t$) is assumed to depend entirely on market fundamentals, where t is measured in days or months, depending on the regression. The market fundamentals include the change in natural gas prices ($\Delta Natural\ Gas_t$), the change in low-sulfur coal prices ($\Delta Coal\ Low\ Sulfur_t$), the change in high-sulfur coal prices ($\Delta Coal\ PA_t$), the change in water levels as a proxy for available hydropower ($\Delta Drought\ Index_t$), and the change in rail freight costs ($\Delta Rail\ Freight\ Costs_t$). Finally, the change in electricity demand ($\Delta Load_t$) controls for daily and seasonal variation in electricity usage due to weather and the economy, among other factors. Model 1 also includes a collection of policy change variables ($Policy_t$).

Market Non-Fundamentals

Model 2 adds the lags of the changes in natural gas, low-sulfur coal, high-sulfur coal, electricity load, drought index, and freight costs. Model 3 adds the lagged change in SO_2 price ($\Delta SO2_{t-1}$). Because Model 1 is nested within Model 2, which in turn is nested within Model 3, the likelihood ratio (LR) test can be used to determine the best performing model. If the LR test indicates that the explanatory power of Model 1 is improved by Model 2 or 3, then that improvement indicates that changes in SO_2 prices are not only induced by changes in the market fundamentals included in Model 1 but might also be driven by fundamental variables omitted from the Model 1 or by forces other than market fundamentals. That is, a significant coefficient on a lagged dependent variable (coupled with an inability to reject Model 3 as an improvement over Model 1) does not necessarily signify that the SO_2 price is driven by non-fundamentals. If the significance of the market fundamental variables remains unchanged after the addition of a lagged explanatory variable, then the lagged variable may simply act as proxy for an omitted fundamental that exhibits autocorrelation. If, however, the lagged dependent variable becomes the significant source of explanatory power (that is, if the significance levels of the market fundamental variables fall), then an inability to reject Model 2 using the LR test probably suggests that the SO_2 price is driven by non-fundamentals rather than market fundamentals.

Finally, as a robustness check on equation (3), we estimate an autoregressive conditional heteroscedasticity (ARCH) model that allows the volatility of the allowance-price time series to vary over time. The variance of the current error term is a function of the squares of previous error terms. We include an ARCH term of order 1, such that the error (ϵ_t) follows a normal distribution with 0 mean and variance σ_t^2, where $\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2$. The ARCH results are consistent with the other regressions (see Appendix Table A-1)..

[13] Most time series analyses include either lagged prices or autoregressive error terms to reduce autocorrelation. This does not present a problem if the main goal of the analysis is price forecasting. Because the lagged dependent variable cannot be interpreted as a market fundamental, including it in a model of price determinants would be inappropriate (Hintermann, 2010).

Volatility

Without making any normative statements about the value of policy changes during the first 15 years of the Acid Rain Program, we construct a test to examine the role of regulatory announcements in determining volatility. Our econometric approach follows on the central bank communication literature as well as the literature of the effect of announcements on the stock and bond market (see, for example, Ederington and Lee, 1993; Fleming and Remolona, 1997; and Bomfim, 2003). We hypothesize that regulatory announcements increase volatility, and we test that hypothesis by regressing the absolute value of the change in log SO_2 prices ($|\Delta SO2_t|$) between days with and without policy announcements.[14]

$$|\Delta SO2_t| = \gamma_0 + \gamma_1 PolicyFixed_t + \gamma_2 PolicyFlexible_t + \gamma_3 ComplianceDate_t + \Delta\epsilon_t \quad (4)$$

In equation (4), $PolicyFixed_t$ refers to policies that are permanent or fixed because they have been legislated, court-ordered, or officially released as final rules by governing agencies; $PolicyFlexible_t$ refers to announcements that represent administrative decisions in which the governing agency or other elected official indicated an intention to change its interpretation of the law or the law itself; and $ComplianceDate_t$ is an indicator variable equal to 1 for the month each year that firms are required to submit allowances to the administrator to compensate for the past year's emissions. We would expect the coefficient on the two policy-change variables to be positive, although the coefficient on $PolicyFixed_t$ should be larger than that on $PolicyFlexible_t$. In an efficient market, $ComplianceDate_t$ should not be significant.

5. Data

The data used in the above regressions come from a variety of sources, as described below. Prices are nominal. Summary statistics for monthly and daily data can be found in Tables 1 and 2, respectively.

Allowance prices. Monthly and daily SO_2 spot prices are shown in Figure 1 and were purchased from Cambridge Energy Research Associates (CERA). Daily SO_2 prices are available from July 31, 2003 to November 30, 2009. Only monthly SO_2 prices are available from the launch of the program in August 1994 to November 2009. Using the augmented Dickey–Fuller test, we find that the first difference of log daily and monthly allowance prices, as well as natural gas and coal prices, electricity usage, drought index, and rail freight producer price index (PPI), are stationary at the 1% significance level in all periods considered.

Natural Gas. The regression equation includes the Bloomberg Natural Gas U.S. average spot price for natural gas (NGUSAVER). It is constructed as a weighted average of the daily spot price for natural gas delivered to more than 20 locations throughout the United States. It ranges from $1.01 per million BTU to $28.38 per million BTU, with an average price of $4.35 per million BTU and would be expected to correlate positively with allowance prices.

[14] We have alternatively specified a model as done in Kohn and Sack (2004), first regressing the change in log price on a constant and then regressing the squared residuals on two indicator variables reflecting the two types of announcements and on two other indicator variables reflecting the week before the two types of announcements. The results from the two approaches are similar.

In theory, the price of both coal prices and natural gas could be determined endogenously with the price of allowances; however, the size of those two fuel markets dwarfs the size of the allowance market, suggesting that any endogeneity in the determination of fuel prices would be small or negligible. For example, in 2009, the value of SO_2 allowances sold during the year was approximately $0.8 billion; the value of natural gas sold was $90 billion and the value of coal was $36 billion (CBO, 2010).[15]

Low-Sulfur Coal. The low-sulfur coal spot price is a Bloomberg index (COALPWDR) for coal (specified as coal delivering at least 8,800 BTU per lb, with less than 0.3 percent sulfur, less than 5.5 percent ash, and less than 30 percent moisture) from the Power River Basin mines in Wyoming and Montana, priced in U.S. dollars per short ton. The prices do not include rail transportation costs from the West to the demand centers in the East. Daily data are available from the beginning of the Acid Rain Program and range from $3.63 per ton to $21.50 per ton, with an average price of $6.35 per ton. Monthly prices are averaged daily prices.

High-Sulfur Coal. The high-sulfur coal spot price is a Bloomberg index (COALPENN) for coal (specified as 12,500 BTU per lb to 13,000 BTU per lb, with 2 to 3 percent sulfur and 7 to 9 percent ash content) mined primarily in the Pittsburgh coal bed, priced in U.S. dollars per short ton. Daily data are available from the beginning of the Acid Rain Program and range from $17.88 per ton to $137.50 per ton, with an average price of $29.71 per ton. Monthly prices are averaged daily prices.

Hydropower. The availability of hydropower is captured by the Palmer Drought Severity Index (PDSI), a meteorological drought index used to assess the severity of a wet or dry spell. The continuous index ranges from -7 to +7, where positive values denote wet spells and negative values denote dry spells.[16] The index is updated on a monthly basis, and we include it in the monthly and daily regressions, assuming publication on the 15th day of each month. We use the PDSI for the Northeast region, which has a significant concentration of both hydropower and coal plants. PDSI data for that region range from -3.9 to 5.5, with an average value of 1.8, suggesting that the Northeast did not, on average, experience drought conditions over the period in question, particularly in the period after May 2003, when values never fell below 0.5.

Rail Freight Costs. The monthly producer price index for rail freight costs was obtained from the Bureau of Labor Statistics (2013). The PPI is available only on a monthly basis; however, rail costs are negotiated in bilateral agreements and contracted escalation rates are often tied to the PPI data. We include rail PPI in the monthly and daily regressions under the assumption that its release represents new information for electricity generators about changes in rail costs.[17] The PPI ranges from 111.3 to 183.3, where December 1984=100, with an average PPI of 129.0.

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[15] According to the U.S. Department of Energy's Energy Information Administration, 1.07 billion tons of coal were produced in 2009 in the United States, with an average price (weighted by coal type) of $33.24, suggesting a market size of approximately $36 billion.

[16] Values from -0.5 to -1.0 indicate incipient drought, -1.0 to -2.0 mild drought, -2.0 to -3.0 moderate drought, -3.0 to -4.0 severe drought, and greater than -4.0 extreme drought.

[17] The BLS line-haul railroad index is published monthly with a one-month lag (Bureau of Labor Statistics, 2013).

Electricity Usage. The demand for electricity is driven by demand to heat and cool buildings, as well as by changing conditions in the economy. The daily or monthly electricity usage for the region extending from Washington, D.C. to Chicago, Illinois, and covering thirteen states was provided by PJM Interconnection (2011). Daily electricity usage, in terawatt-hours, over the period ranged from 0.55 TW-hr per day to 1.25 TW-hr per day, and averaged 0.78 TW-hr per day. The power plants in the PJM region accounted for 55 percent of U.S. SO_2 emissions in 2000 (Energy Information Administration, 2011). The change in daily demand was constructed by subtracting the moving average of the electricity usage for the seven previous days from the current daily demand, and then lagging the result by one day to reflect the fact that the allowance price in any day is based on knowledge gained from the previous day's electricity usage. The moving average construction of the variable smooths expectations from day to day. For the monthly demand variable, demand is differenced between months.

In theory, electricity usage is endogeneous to SO_2 allowance prices because allowance prices would be reflected in electricity prices. However, the potential endogeneity is mitigated by the fact that the size of the SO_2 allowance market ($0.8 billion per year) is very small compared with the size of the electricity market (over $350 billion nationally in 2012), and thereby that fluctuations in SO_2 prices would not be expected to affect electricity prices (EIA, 2013).

Regulatory Policy Announcements

The policy announcements for NAAQS, CAIR, and Clear Skies are summarized in two policy variables. Policy announcements are described as "tightening" the standard (i.e., making allowances more expensive) or as "loosening" the standard (making allowances less expensive) (see Table 3). Each announcement is included as an indicator variable in the regression equal to 1 for the day the announcement was made and 0 otherwise. Figure 1 shows the SO_2 price index along with announcement dates.

We also constructed a variable called $PolicyPerm_t$ equal to 1 when the announced policy signaled a more permanent structural change, and a variable called $PolicyFlexible_t$, equal to 1 when the announced policy was of an administrative nature, not finalized, or representative of some flexibility in the governing agency's interpretation of the governing law. Table 3 summarizes how each announcement was categorized. Specifically, the issuance of proposals and rules by the EPA or by court decisions were denoted as policy changes, and non-binding proposals, clarification of past proposals, or the re-evaluation of rules were categorized as administrative announcements.

6. Results and Discussion

As described earlier, the SO_2 price data exist on a monthly basis over the 15 years of the program, but on a daily basis starting only on July 31, 2003. We begin by analyzing monthly data through the end of 2009 and daily data over the period they are available.

We find that market fundamentals play an important and significant role in determining allowance prices over the duration of the program. Although they do not describe every fluctuation in allowance prices or completely explain the sudden increase in prices that occurred in 2003, fundamentals do explain a substantial share of price movements over the full period of analysis. Then we use the LR test to determine whether there exist breaks in the data—where market fundamentals become a more (or less) significant factor in determining allowance prices. With respect to the daily data, we identify a break in July 2008, when the courts struck down CAIR, after which market fundamentals appear to play a different role in determining allowance prices. Using the monthly data, we identify a second break at the end of 1998, before which market fundamentals appear to play a less significant role in determining allowance prices. We present results from each of those analyses.

Full Program Analysis

Monthly. Market fundamentals (as shown in Model 1) are largely significant—both statistically and economically—between August 1994 and November 2009, a period that represents the full monthly data set (see Table 4). All of the coefficients, with the exception of drought index, have the expected sign, and four are statistically significant; the coefficient on the drought index is not statistically significant. In aggregate, the fundamentals represent about 26 percent of the variation in allowance prices. The results suggest that a one dollar monthly increase in the price of substitute fuels raises allowance prices by 2 percent (natural gas) and 3 percent (low-sulfur coal) and a one dollar increase in high-sulfur coal prices reduces allowance prices by 0.5 percent. A one unit increase in the rail cost index increases allowance prices by 2 percent.

The addition of lagged independent variables (Model 2) does not represent an improvement on Model 1, as shown by the LR test comparing the two models (*p*-value of 0.36). The sign, significance, and magnitude of most variables remain unchanged, further suggesting that the lagged variables do not add information to the model. Finally, adding the lagged dependent variable (Model 3) improves on Model 2 (*p*-value of 0.0002) and on Model 1 (*p*-value of 0.0045) suggesting that over the whole period, non-fundamentals may influence allowance prices. However, the coefficients on the market fundamental variables are largely unchanged, which may also indicate that the lagged dependent variable is correlated with an omitted variable.

Daily. Performing the same analysis for the daily data—between July 31, 2003 and November 30, 2009—leads to a similar conclusion (see Table 5). Market fundamentals are largely of the expected sign and are significant, both statistically and economically (Model 1); rail freight is the only fundamental not of the anticipated sign, but also not statistically significant. The magnitude of the coefficients in the models based on daily data is lower than the magnitude of the coefficients based on monthly data, reflecting the fact that electricity generators have more flexibility over the course of a month than they do over the course of a day, as would be expected.

The addition of lagged fundamentals (Model 2) does not improve on Model 1 (*p*-value of 0.34), but adding the lagged dependent variable (Model 3) does appear to improve on Model 1 (*p*-value of 0.002). However, inclusion of the lagged dependent variable does not change the sign, significance, or magnitude of any of the fundamentals, suggesting that fundamentals are an important explanatory source of price, but the lagged dependent variable may be correlated with an omitted variable. To resolve this, we analyze potential structural breaks in the program.

Structural Breaks

CAIR Remanded. On July 11, 2008, the U.S. Court of Appeals vacated and struck down CAIR, which was to govern the market (and tighten the cap) after 2010. The court granted a request for a rehearing, but not for six months subsequent to its ruling. The unexpected court decision sent allowance prices down almost 60 percent overnight and introduced significant uncertainty about whether the Acid Rain Program would continue beyond 2010. A more important consideration was that the decision introduced uncertainty about the value of the large bank of allowances that regulated firms had amassed. Then, on December 23, 2008, the court allowed the EPA to continue with the implementation of CAIR until the court could issue a new ruling by July 2010.

Given the importance of that 2008 decision in determining future compliance stringency, we include July 11, 2008 as a structural break in the data. Examining the role of fundamentals in the daily data in the period before CAIR was remanded (Table 6), we see that the coefficients on the market fundamentals are similar to those in Table 5. Neither the addition of lagged fundamentals (Model 2, with p-value of 0.925) nor the addition of the lagged dependent variable (Model 3, with p-value of 0.940) improves on Model 1. This lack of improvement in the model signifies that market fundamentals were the main drivers of allowance price movements before CAIR was remanded in July 2008. In addition, the fundamentals increased the explanatory power of the model from 8 percent (Model 1 of Table 5) to 21 percent (Model 1 of Table 6).

Without clear market rules, particularly between July and December 2008, one would expect allowance prices to be less likely to follow market fundamentals. In the period after the CAIR remanding, from July 2008 through November 2009, the coefficients are not significant, although all of the fundamentals except the coal variables have the predicted sign (see Appendix Table A-2).

Market Launch. Hintermann (2010) concluded that allowance prices over the first few years of the European carbon market were driven less by fundamentals and more by momentum or another non-fundamental market activity. We test for an equivalent start-up phase in the SO_2 market, using the monthly data (see Appendix Table A-3), assuming a four-year start-up period, and find that market fundamentals played a lesser role during the initial years of the program. In the Acid Rain Program, there was no obvious point in time when the market transitioned from start-up to mature. We selected four years because, for periods longer than four years, market fundamentals played an increasingly stronger role but the role of market fundamentals was mixed for periods shorter than four years. That period also corresponds to the time when EPA noted that transaction costs were high.

For the first four years of the program, we find that the independent variables have limited predictive content related to allowance prices. When lagged independent variables are added (Model 2), the explanatory power of the model increases (p-value of 0.05). Adding the lagged dependent variable (Model 3) causes the explanatory power of the model to increase yet further (p-value of 0.00). Such results strongly suggest that, in the first few years of the Acid Rain Program, market fundamentals played only a small role in determining allowance prices.

Policy Uncertainty and SO_2 Price Volatility

The second contribution of this paper is an analysis of the magnitude of the effect of regulatory uncertainty on increased volatility, as established by the results from Equation 2 (see Table 7). Any announcement that affects the program fundamentals would be expected to change the price of allowances, and thus, increase volatility. As expected, we find in Table 7 that regulatory announcements are associated with a positive and significant increase in volatility (as measured by the absolute value of the difference in log price). We also find, however, that there is a difference between more permanent, structural policy announcements (those described as "Permanent" in Table 3) and administrative signals (those described as "Flexible" in Table 3). Permanent policy announcements increase daily and monthly volatility more than flexible announcements do, and by a large and significant amount.

Administrative announcements do not necessarily represent permanent changes to the statute, but instead constitute only an intention by the governing agency or other official to change the program. We find that they increase daily volatility by a smaller but still statistically significant amount. And we find that their influence on volatility was smaller during the period when market fundamentals were more important (2003 to 2008). The magnitude of the volatility induced by administrative announcements compared with structural announcements is similar to that found by other researchers for central bank announcements that were official communications compared with communications not intended to convey new policy (for example, interviews by the Chairman of the Federal Reserve) (Kohn and Sack, 2004).

The fact that such administrative announcements move the market price of allowances is not surprising. For example, an article about the cap-and-trade program in California prior to launch quoted a trader as saying, "we're poring through every seemingly simple announcement looking for any clues to a potential delay" (Doan and Chediak, 2012). Similarly, in May 2012, a commissioner of the European Union's carbon market caused EU allowance prices to move temporarily when he said "I am willing to support . . . to come to a price signal of EUR10 or more, which is good for investment in clean energy" (Torella, 2012).

As new information about the costs and benefits of any cap-and-trade program become available, regulators or legislators may want to alter the structure of the market to respond to that new information, even if the increased volatility induced by the change increases uncertainty and reduces investment in the near term. Some such changes, particularly those that originate in the legislature, may not be amenable to an announcement policy; legislators do not often offer notice to traders that they will be making market-moving statements. However, the fact that market participants are listening to all types of announcements and adjusting their expectations about price suggests that frequent announcements of a non-permanent, administrative, or speculative nature could probably increase the volatility of the market more than is intended by market administrators. Following the example of central banks, the EU Emissions Trading System has addressed some of those concerns by implementing a series of measures to control the release of information to the market. Prior to the release of new official information, it releases a pre-announcement that notifies market participants that new information is forthcoming. That puts everyone in the market on equal footing with respect to receiving the new information, and elevates the new information to a higher level of importance. To avoid leaking the information to the market, a limited number of people have access to the information contained in the ultimate release. It also has a process for amending the implementing legislation, which in Phase 3 of the program involved the release of draft rules to the general public at the same time the rules were submitted to member states for discussion and vote.

The objective of any communication policy is not to prevent the administering or legislative body from changing the rules of the market, but to reduce the volatility created by communications with low signal-to-noise value. If the United States were to adopt a larger cap-and-trade program, such as one for carbon, market efficiency might be improved by also adopting a clear policy for releasing new information about the market and for making changes to the market rules.

7. Conclusion

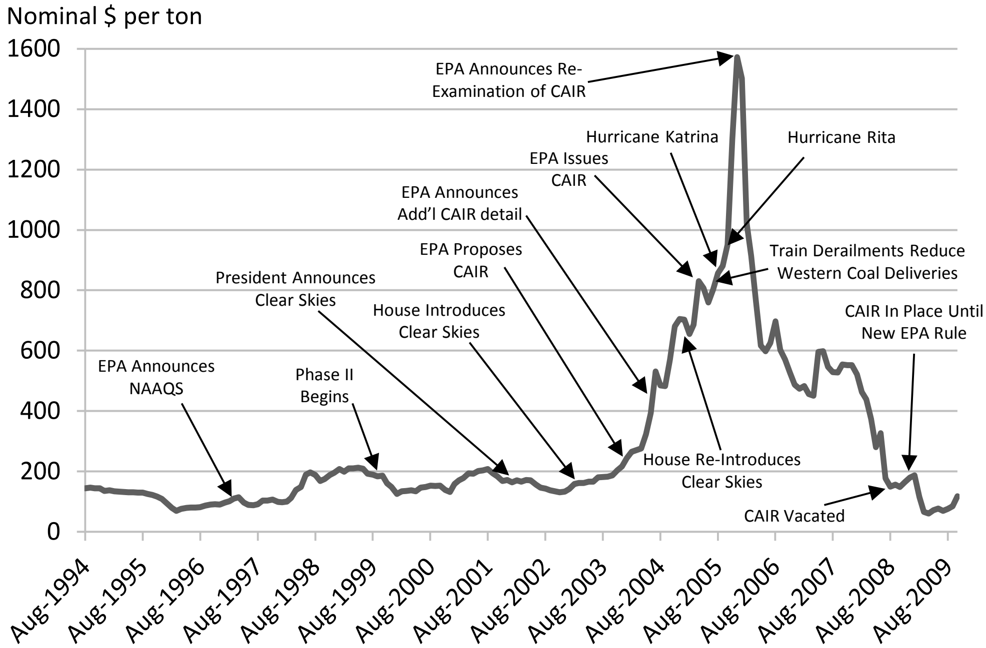
The sulfur dioxide market for emissions allowances is the oldest cap-and-trade market in the United States, and it offers useful lessons for the design of future emissions markets. We find that as the program progressed, market fundamentals played an increasingly dominant role in determining allowance price changes. We also find that administrative, non-permanent announcements during that period introduced uncertainty into the marketplace—uncertainty that (following economic theory) likely reduced investment in the adoption of low cost emission-reducing technologies.

Several conclusions can be drawn from these results. First, regardless of the sophistication of market participants, new markets are likely to take some time to achieve efficient operation. We found this to be true for the sulfur dioxide market (which included many sophisticated market participants accustomed to trading electricity on active markets). Other researchers have found similar results for the European emissions market (Hintermann, 2010). That conclusion could suggest that cap-and-trade markets require more educational support or other aids during the start-up period.

Second, although policy makers are likely to continue to want to change or improve market-based programs after the programs have launched, any public discussion of changes is very likely to induce volatility into the market. That volatility would be reduced if regulators implement a communication policy that adopts practices from central banks and other market-moving agencies to the context of environmental markets, with the objective of releasing information to the market in a predictable, controlled, and highly transparent manner. The literature does not present a set of best practices for communication strategy, but instead discusses a variety of approaches used by market-moving institutions. Similarly, it is beyond the scope of this paper to suggest the best communication policies for regulators of environmental markets in the United States. A variety of policies might be appropriate, depending on the type and frequency of announcements anticipated by the regulators. For example, regulators could state that the market rules will not be revisited more than once a year. Alternatively, they could issue a pre-announcement statement notifying interested parties that potentially market-moving information will be released to the public at a specific time. That latter practice is currently used by the U.S. Federal Reserve and by regulators of the EU Emissions Trading System. The words of Janet Yellen that “clear communication is itself a vital tool for increasing the efficacy and reliability [of markets]” might guide the selection of specific communications policies.

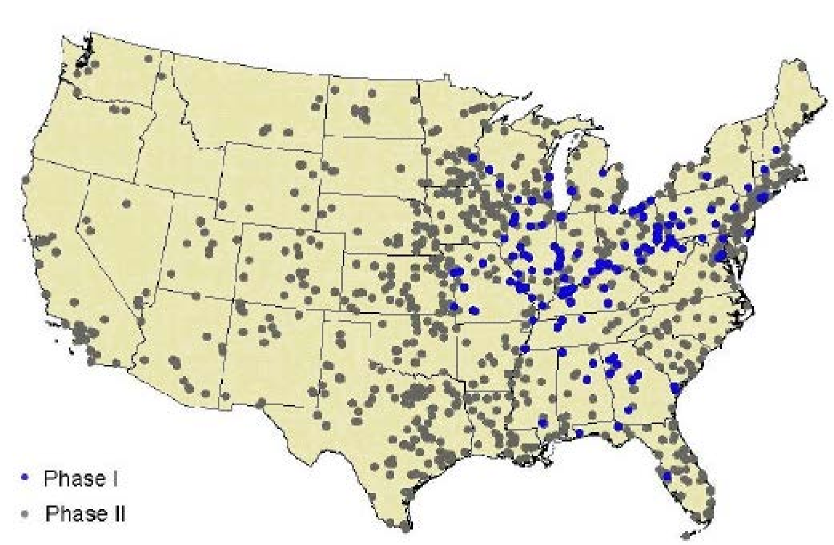
Figures

Figure 1. Index of Monthly SO_2 Allowance Prices and Policy Announcements, 1994 to 2009



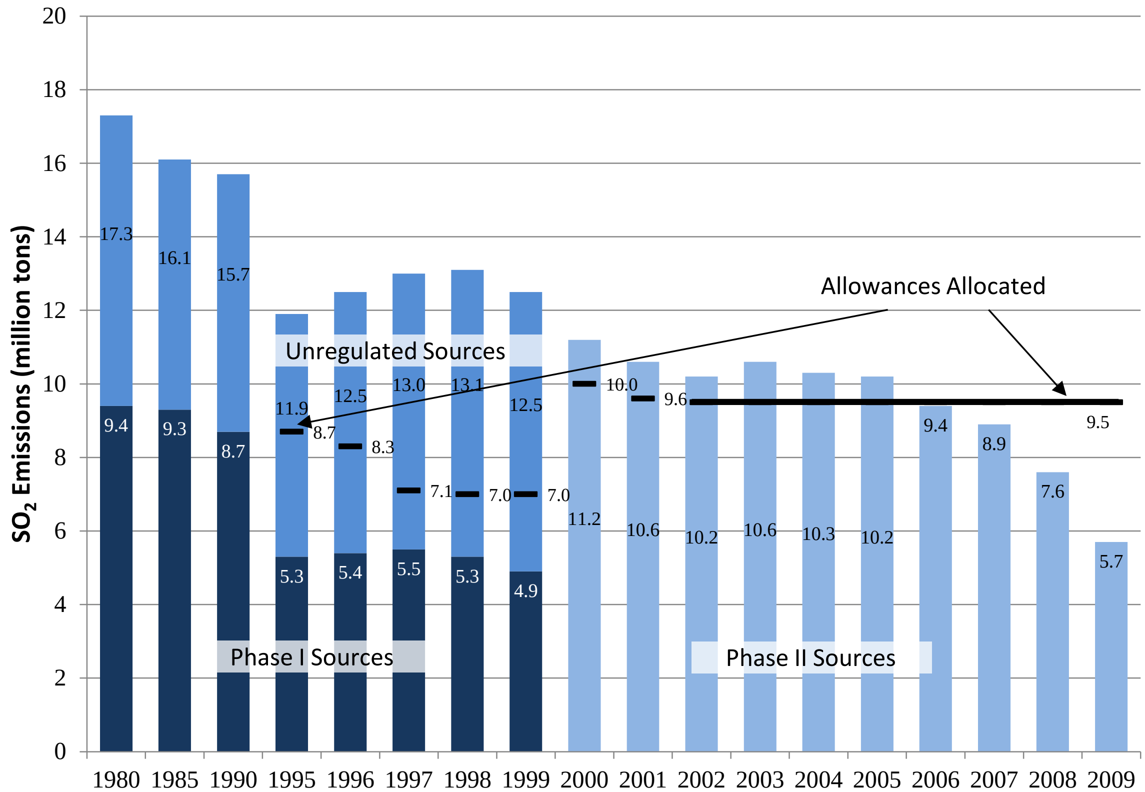
Source: Cambridge Energy Research Associates and Congressional Budget Office.

Figure 2. Power Sector Emission Sources Covered by the Acid Rain Program



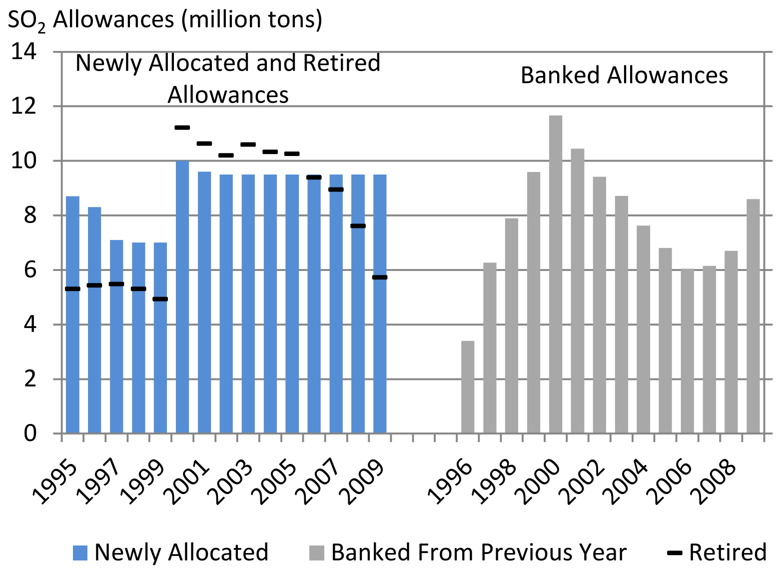
Source: Environmental Protection Agency (2002).

Figure 3. SO_2 Emissions from Acid Rain Program Sources, 1980 to 2009



Note: Unregulated sources are those sources that are not regulated in Phase I, but would become regulated under Phase II. Phase I Sources include those sources that voluntarily joined the program.
Source: Environmental Protection Agency (2010).

Figure 4. SO_2 Allowance Banking and Size, 1995 to 2009



Source: Environmental Protection Agency (2010).

Tables

Table 1. Summary Statistics for Monthly Data

Variable	Mean	Std. Dev.	Min	Max
D.SO_2 Monthly Price (Log)	-0.0031	0.124	-0.612	0.331
D.Natural Gas	0.0135	0.956	-4.36	3.28
D.Coal Low Sulfur	0.0135	0.929	-3.61	5.5
D.Coal High Sulfur	0.142	3.83	-24	15
D.Electricity Load	0.0148	2.48	-7.15	5.46
D.Drought Index	0.00736	1.06	-3.55	5.29
D.Rail Freight PPI	0.307	1.17	-4.8	4.5
Volatility	0.0794	0.0951	5.44E-05	0.612

Note: "D." denotes a differenced variable. See the paper for the explanation of differencing for each variable. Data cover the period 9/1/1994 through 11/30/2009.

Table 2. Summary Statistics for Daily Data

Variable	Mean	Std. Dev.	Min	Max
D.SO_2 Daily Price (Log)	-0.00034	0.0365	-0.847	0.506
D.Natural Gas	-0.00029	0.687	-21.5	12.4
D.Coal Low Sulfur	0.00105	0.272	-3	5
D.Coal High Sulfur	0.00912	1.34	-25	21.5
D.Electricity Load	-0.00033	0.0732	-0.268	0.297
D.Drought Index	0.00109	0.144	-1.47	2.6
D.Rail Freight PPI	0.0198	0.333	-4.8	4.5
Volatility	0.00949	0.0353	0	0.847

Note: "D." denotes a differenced variable. See the paper for the explanation of differencing for each variable. Data cover the period 8/2/2003 through 11/30/2009.

Table 3. Policy Announcements

Num[a]	Date	Policy	Event	Response of SO_2 Cap	Announcement Type[b]
1	03/13/1997	NAAQS	EPA announces it intends to tighten particulate matter (PM) standards (and introduce a new PM2.5 standard).	Loosen	Flexible
2	02/14/2002	Clear Skies	President Bush announces the Clear Skies Act.	Tighten	Flexible
3	07/26/2002	Clear Skies	The House introduces the Clear Skies Act of 2002.	Tighten	Flexible
4	01/04/2005	Clear Skies	Re-introduced in House as Acid Rain Control Act.	Tighten	Flexible
5	12/17/2003	CAIR	EPA first proposes the Clean Air Interstate Rule (CAIR).	Tighten	Permanent
6	05/28/2004	CAIR	EPA Supplemental Proposal provides additional details.	Tighten	Flexible
7	03/10/2005	CAIR	EPA issues the Clean Air Interstate Rule.	Tighten	Permanent
8	11/22/2005	CAIR	After receiving 11 petitions for reconsideration, the EPA agrees to review and reconsider CAIR.	Loosen	Flexible
9	07/11/2008	CAIR	U.S. Court of Appeals vacates and remands CAIR. However, a request for a rehearing is also granted.	Loosen	Permanent
10	12/23/2008	CAIR	CAIR is in place until EPA issues new rule to replace CAIR in two years.	Tighten	Flexible
11	07/06/2010	TR	The EPA proposes the Transport Rule to replace CAIR.	NA	NA

Note: a) Row numbers are referenced in subsequent tables. b) Fixed announcements represent permanent, structural changes that have been legislated, court-ordered, or officially released as final rules. Flexible announcements represent administrative decisions in which the governing agency had some flexibility in implementation or interpretation of the law.
NA=not applicable.

Table 4. Determinants of the Monthly SO_2 Price (All Periods, 1994 to 2009)

Dependent Variable:	August 1994 to November 2009		
D.SO_2 Monthly Price (Log)	Model 1	Model 2	Model 3
D.Natural Gas	0.0239**	0.0259***	0.0258***
	(2.58)	(2.70)	(2.78)
D.Low-Sulfur Coal	0.0320***	0.0280**	0.0184*
	(3.30)	(2.59)	(1.71)
D.High-Sulfur Coal	-0.00536**	-0.00649**	-0.00509**
	(-2.21)	(-2.52)	(-2.02)
D.Electricity Load	0.00153	0.00117	0.00135
	(0.45)	(0.34)	(0.40)
D.Drought Index	0.00305	0.00316	0.00491
	(0.40)	(0.40)	(0.64)
D.Rail Freight PPI	0.0247***	0.0158	0.0139
	(3.04)	(1.65)	(1.50)
LD.Natural Gas		0.00837	0.00359
		(0.88)	(0.39)
LD.Low-Sulfur Coal		-0.00587	-0.0136
		(-0.63)	(-1.48)
LD.High-Sulfur Coal		0.00244	0.00393
		(0.83)	(1.38)
LD.Electricity Load		0.00201	0.00194
		(0.56)	(0.56)
LD.Drought Index		0.00751	0.00625
		(0.96)	(0.82)
LD.Rail Freight PPI		0.0129	0.00996
		(1.38)	(1.09)
LD.SO_2 Monthly Price (Log)			0.258***
			(3.55)
Constant	-0.0107	-0.0125	-0.0107
	(-1.28)	(-1.47)	(-1.29)
Policy Announcements	9↓***	9↓***	8↑*, 9↓***
Observations	182	182	182
Log Likelihood	158.5	161.8	168.8
Adjusted R-squared	0.263	0.263	0.313
p-value	0.0000	0.0000	0.0000
LR test (vs. Model 1) *p*-value		0.3600	0.0045
LR test (vs. Model 2) *p*-value			0.0002

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.
"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.
t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.
PPI=producer price index.

Table 5. Determinants of the Daily SO_2 Price (2003 to 2009)

Dependent Variable:	31 July 2003 to 30 November 2009		
D.SO_2 Daily Price (Log)	Model 1	Model 2	Model 3
D.Natural Gas	0.00265**	0.00281***	0.00283***
	(2.48)	(2.62)	(2.64)
D.Low-Sulfur Coal	0.000410	0.000534	0.000838
	(0.15)	(0.20)	(0.31)
D.High-Sulfur Coal	-0.00141**	-0.00136**	-0.00128**
	(-2.53)	(-2.43)	(-2.30)
D.Electricity Load	0.0215**	0.0168	0.0164
	(2.16)	(1.30)	(1.28)
D.Drought Index	-0.00321	-0.00322	-0.00314
	(-0.63)	(-0.63)	(-0.62)
D.Rail Freight PPI	-0.000942	-0.000635	-0.000801
	(-0.43)	(-0.29)	(-0.36)
LD.Natural Gas		0.00170	0.00191*
		(1.58)	(1.79)
LD.Low-Sulfur Coal		-0.0000362	0.00000105
		(-0.01)	(0.00)
LD.High-Sulfur Coal		0.000915	0.000800
		(1.64)	(1.44)
LD.Electricity Load		0.00780	0.0102
		(0.60)	(0.79)
LD.Drought Index		-0.00470	-0.00493
		(-0.92)	(-0.97)
LD.Rail Freight PPI		-0.00132	-0.00143
		(-0.60)	(-0.65)
LD.SO2 Daily Price (Log)			-0.0849***
			(-4.06)
Constant	-0.00000767	0.0000124	0.0000136
	(-0.01)	(0.02)	(0.02)
Policy Announcements	9↓***, 10↑**	9↓***, 10↑**	9↓***, 10↑***
Observations	2313	2313	2313
Log Likelihood	4478.9	4482.3	4490.6
Adjusted R-squared	0.0823	0.0826	0.0888
p-value	0.0000	0.0000	0.0000
LR test (vs. Model 1) *p*-value		0.3441	0.0015
LR test (vs. Model 2) *p*-value			0.0000

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.
"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.
t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.
PPI=producer price index.

Table 6. Determinants of the Daily SO_2 Price (2003 to 2008)

Dependent Variable: D.SO_2 Daily Price (Log)	31 July 2003 to 11 July 2008		
	Model 1	Model 2	Model 3
D.Natural Gas	0.00238***	0.00246***	0.00246***
	(2.68)	(2.76)	(2.76)
D.Low-Sulfur Coal	0.00454*	0.00463*	0.00473*
	(1.85)	(1.88)	(1.92)
D.High-Sulfur Coal	-0.00283***	-0.00279***	-0.00279***
	(-4.12)	(-4.05)	(-4.05)
D.Electricity Load	0.0152*	0.00898	0.00900
	(1.76)	(0.80)	(0.80)
D.Drought Index	-0.00164	-0.00162	-0.00160
	(-0.37)	(-0.37)	(-0.36)
D.Rail Freight PPI	-0.00284	-0.00267	-0.00269
	(-1.25)	(-1.16)	(-1.17)
LD.Natural Gas		0.000978	0.00102
		(1.10)	(1.14)
LD.Low-Sulfur Coal		0.000135	0.000177
		(0.06)	(0.07)
LD.High-Sulfur Coal		-0.0000333	-0.0000339
		(-0.05)	(-0.05)
LD.Electricity Load		0.00963	0.00988
		(0.85)	(0.87)
LD.Drought Index		-0.000403	-0.000425
		(-0.09)	(-0.10)
LD.Rail Freight PPI		-0.000687	-0.000734
		(-0.30)	(-0.32)
LD.SO_2 Daily Price (Log)			-0.0167
			(-0.61)
Constant	0.000418	0.000427	0.000431
	(0.64)	(0.64)	(0.65)
Policy Announcements	9↓***	9↓***	9↓***
Observations	1806	1806	1806
Log Likelihood	3924.7	3925.7	3925.9
Adjusted R-squared	0.213	0.212	0.211
p-value	0.0000	0.0000	0.0000
LR test (vs. Model 1) *p*-value		0.9250	0.9404
LR test (vs. Model 2) *p*-value			0.5415

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.
"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.
t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.
PPI=producer price index.

Table 7. Determinants of Volatility

Dependent Variable: Volatility (Daily or Monthly)	Full Daily 31 July 2003 to 30 November 2009	Period 1 Daily 31 July 2003 to 11 July 2008	Period 2 Daily 12 July 2008 to 30 November 2009	Full Monthly August 1994 to November 2009
Flexible announcement	0.0411**	0.00669	0.144***	0.0256
	(2.43)	(0.42)	(2.91)	(0.71)
Permanent announcement	0.282***	0.283***		0.168***
	(14.44)	(17.67)		(3.12)
Compliance deadline	0.00161	-0.000731	0.0150	0.0427*
	(0.43)	(-0.22)	(1.12)	(1.70)
Constant	0.00899***	0.00817***	0.0118***	0.0718***
	(12.54)	(12.28)	(5.32)	(9.86)
Observations	2314	1807	507	183
Log Likelihood	4558.7	3920.9	807.0	178.1
Adjusted R-squared	0.0837	0.146	0.0150	0.0524
F-test *p*-value	0.0000	0.0000	0.0083	0.0055

t-statistics are in parentheses; * 0.1 ** 0.05 *** 0.01.

When monthly data are used, the compliance deadline is an indicator variable equal to 1 during the month of February. When daily data are used, the compliance deadline is equal to 1 during the second half of February. Those values control for the compliance deadline on March 1st of every year.

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Appendix

Table A-1. ARCH Model of the Determinants of the Daily SO_2 Price (2003 to 2008)

Dependent Variable:	31 July 2003 to 11 July 2008		
D.SO_2 Daily Price (Log)	Model 1	Model 2	Model 3
D.Natural Gas	0.00209***	0.00216***	0.00217***
	(3.00)	(2.88)	(2.86)
D.Low-Sulfur Coal	0.00268	0.00280	0.00266
	(0.94)	(0.91)	(0.88)
D.High-Sulfur Coal	-0.000263	-0.000218	-0.000222
	(-0.25)	(-0.20)	(-0.21)
D.Electricity Load	0.0136	0.00933	0.00938
	(1.49)	(0.75)	(0.76)
D.Drought Index	-0.00165	-0.00164	-0.00169
	(-0.13)	(-0.12)	(-0.13)
D.Rail Freight PPI	-0.00235	-0.00227	-0.00224
	(-1.49)	(-1.43)	(-1.40)
LD.Natural Gas		0.00118	0.00103
		(1.17)	(0.96)
LD.Low-Sulfur Coal		0.000161	0.0000707
		(0.00)	(0.00)
LD.High-Sulfur Coal		-0.0000421	-0.0000351
		(-0.00)	(-0.00)
LD.Electricity Load		0.00680	0.00692
		(0.55)	(0.55)
LD.Drought Index		-0.000273	-0.000210
		(-0.04)	(-0.03)
LD.Rail Freight PPI		-0.000651	-0.000648
		(-0.07)	(-0.08)
LD.SO_2 Daily Price (Log)			0.0478
			(0.92)
Constant	0.000104	0.000166	0.000191
	(0.18)	(0.26)	(0.30)
Policy Announcements	9↓***	9↓***	9↓***
L.ARCH	0.262***	0.261***	0.258***
	(16.63)	(16.51)	(14.18)
ARCH Constant	0.000524***	0.000524***	0.000523***
	(138.22)	(140.34)	(140.15)
Observations	1806	1806	1806
Log Likelihood	4162.0	4163.2	4163.7
Adjusted R-squared	0.0000	0.0000	0.0000
p-value		0.8825	0.8340
LR test (vs. Model 1) *p*-value			0.2857
LR test (vs. Model 2) *p*-value			0.2857

ARCH = Autoregressive Conditional Heteroskedasticity

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.

"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.

t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.

PPI=producer price index.

Table A-2. Determinants of the Daily SO_2 Price (2008 to 2009)

Dependent Variable:	31 July 2008 to 30 November 2009		
D.SO_2 Daily Price (Log)	Model 1	Model 2	Model 3
D.Natural Gas	0.00517	0.00701	0.00703
	(0.99)	(1.32)	(1.32)
D.Low-Sulfur Coal	-0.00936	-0.0104	-0.0105
	(-1.03)	(-1.14)	(-1.14)
D.High-Sulfur Coal	0.000150	0.000166	0.000165
	(0.14)	(0.15)	(0.15)
D.Electricity Load	0.0589*	0.0505	0.0504
	(1.66)	(1.14)	(1.14)
D.Drought Index	-0.0135	-0.0127	-0.0127
	(-0.73)	(-0.69)	(-0.68)
D.Rail Freight PPI	0.00276	0.00575	0.00574
	(0.55)	(1.10)	(1.10)
LD.Natural Gas		0.0109*	0.0109*
		(1.96)	(1.96)
LD.Low-Sulfur Coal		0.000876	0.000852
		(0.10)	(0.09)
LD.High-Sulfur Coal		0.000194	0.000194
		(0.18)	(0.18)
LD.Electricity Load		0.0138	0.0140
		(0.31)	(0.32)
LD.Drought Index		-0.0275	-0.0276
		(-1.48)	(-1.48)
LD.Rail Freight PPI		-0.00424	-0.00423
		(-0.82)	(-0.82)
LD.SO2 Daily Price (Log)			-0.00254
			(-0.06)
Constant	-0.000959	-0.000695	-0.000698
	(-0.42)	(-0.30)	(-0.30)
Policy Announcements	9↑*	9↑*	9↑*
Observations	507	507	507
Log Likelihood	790.9	794.0	794.0
Adjusted R-squared	0.00123	0.00121	-0.000821
p-value	0.377	0.408	0.483
LR test (vs. Model 1) *p*-value		0.4086	0.5241
LR test (vs. Model 2) *p*-value			0.9543

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.
"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.
t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.
PPI=producer price index.

Table A-3. Determinants of the Monthly SO_2 Price (1994 to 1998)

Dependent Variable:	August 1994 to December 1998		
D.SO_2 Monthly Price (Log)	Model 1	Model 2	Model 3
D.Natural Gas	-0.0200	-0.0203	-0.0424
	(-0.60)	(-0.51)	(-1.27)
D.Low-Sulfur Coal	-0.0947	-0.179**	-0.198***
	(-1.45)	(-2.29)	(-3.06)
D.High-Sulfur Coal	-0.0134	-0.0167	-0.00835
	(-0.54)	(-0.69)	(-0.41)
D.Electricity Load	-0.00504	-0.00295	-0.00841
	(-0.86)	(-0.45)	(-1.50)
D.Drought Index	0.00214	-0.00485	0.00385
	(0.20)	(-0.46)	(0.43)
D.Rail Freight PPI	0.0205	0.0459	0.0535
	(0.31)	(0.71)	(1.00)
LD.Natural Gas		-0.106**	-0.0854**
		(-2.34)	(-2.27)
LD.Low-Sulfur Coal		-0.0135	0.0586
		(-0.18)	(0.93)
LD.High-Sulfur Coal		-0.0236	-0.0266
		(-0.83)	(-1.13)
LD.Electricity Load		-0.00524	-0.00138
		(-0.84)	(-0.26)
LD.Drought Index		-0.000952	0.00129
		(-0.09)	(0.14)
LD.Rail Freight PPI		0.114*	0.103*
		(1.72)	(1.89)
LD.SO_2 Monthly Price (Log)			0.553***
			(4.25)
Constant	0.000355	-0.00469	-0.00425
	(0.03)	(-0.38)	(-0.42)
NAAQS Announced 03/1997	0.0777	-0.0633	-0.0371
	(0.92)	(-0.59)	(-0.42)
Observations	51	51	51
Log Likelihood	59.38	65.58	75.97
Adjusted R-squared	-0.0593	0.0348	0.340
p-value	0.752	0.360	0.00586
LR test (vs. Model 1) *p*-value		0.0534	0.0000
LR test (vs. Model 2) *p*-value			0.0000

"D." denotes a differenced variable; "LD." denotes a one-period lag of a differenced variable. See the paper for the explanation of differencing for each variable.
"Policy Announcements" includes each relevant policy announcement in the regression from Table 3 and lists the sign and significance of each announcement (by number) that is significant.
t-statistics are in parentheses; * 0.1; ** 0.05; *** 0.01.
PPI=producer price index.