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Should we be worried about the green paradox? Announcement effects of the Acid Rain Program ☆

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ABSTRACT

This paper presents the first empirical test of the green paradox hypothesis, according to which well-intended but imperfectly implemented environmental policies may lead to detrimental outcomes due to supply side responses. We use the introduction of the Acid Rain Program in the U.S. as a case study. The theory predicts that owners of coal deposits, expecting future sales to decline, would supply more of their resource between the announcement of the Acid Rain Program and its implementation; moreover, the incentive to increase supply would be stronger for owners of high-sulfur coal. This would, all else equal, induce an increase in sulfur dioxide emissions. Using data on prices, heat input and sulfur content of coal delivered to U.S. power plants, we find strong evidence of a price decrease and of an increase in the sulfur premium, some indication that the amount of coal used might have increased, and no evidence of fuel-switching towards higher-sulfur coal. Overall, our evidence suggests that while the mechanism indicated by the theory might be at work, market conditions and concurrent regulation largely prevented a green paradox from arising. These results have implications for the design of climate policies.

1. Introduction

Like any other policy aimed at correcting externalities, environmental policy may have unintended detrimental effects if it is not optimally designed to take into account behavioral changes on the part of the regulated agents. A text-book example of such a phenomenon occurs when regulators want to control fishing efforts mandating maximum levels for the use of specific inputs (e.g. fishing time, number of vessels, type of fishing gear, etc.). Rationally, fishermen react by substituting away from the regulated inputs into permissable ones, and the excessive pressure on the fish populations does not abate (Tietenberg and Lewis, 2012). Another well-known example is the impact of the Endangered Species Act (ESA) on land-owners' incentives to preserve undeveloped land. If an endangered species is found or expected to be found on a piece of land, the landowner faces a significant reduction in the value of the land as he loses the option to develop. Hence, when an endangered species approaches a parcel stocked with valuable timber (effectively acting as an announcement of future land-

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use regulations prescribed under the ESA), land-owners have an incentive to preemptively destroy the species' habitat (Lueck and Michael, 2003; Zhang, 2004).

The notion that regulated agents may respond to environmental policy differently than anticipated by policymakers has recently received renewed attention, thanks to the thought-provoking contributions by Hans-Werner Sinn (2008, 2012). Sinn argues that most climate policies currently implemented not only fail to provide a solution to the problem of increasing greenhouse gas emissions, but actually aggravate the problem by providing perverse incentives to the owners of stocks of fossil fuels, an outcome he called a 'green paradox'. The crux of Sinn's argument is that resource owners rationally change their behaviour in response to the introduction of environmental policy: as the regulation threatens to reduce future profits, resource owners may modify their extraction plans to increase near-term supply, which increases emissions. When policymakers fail to take into account this type of rational response to the policy shock, the realized effect of the policy on the path of emissions may not be the desired one. Sinn's seminal contribution has spawned a rich theoretical literature, which discusses several mechanisms that might lead to a green paradox (see e.g. Eichner and Pethig, 2011; Gerlagh, 2011; Grafton et al., 2012; Di Maria et al., 2012; Fischer and Salant, 2012; Hoel, 2012b; Smulders et al., 2012; Van der Ploeg and Withagen, 2012).

Until now, no empirical investigation has addressed the crucial question whether the effects suggested by Sinn (2008, 2012) and others give cause for concern, or are likely to be tempered by other features of actual markets. This paper fills this gap by presenting what is, to our knowledge, the first empirical test of the green paradox hypothesis.

We study changes in the price, quantity and quality of the coal delivered to U.S. power plants in the period between the signing into law of the 1990 Clean Air Act Amendments (CAAA, Public Law 101-549), and the implementation of the Acid Rain Program (ARP) in 1995.[1] The announcement of the Acid Rain Program (regulated by Title IV of the 1990 CAAA) allows us to test four hypotheses that follow from the theory of the green paradox literature.[2] The announcement acted as a signal to owners of stocks of coal that it would be harder to sell their product from 1995 onwards: as it put a nation-wide limit on sulfur-dioxide (SO_2) emissions, the future prospects for coal were consequently restricted.[3] According to the green paradox hypothesis sketched above, this would have given mine owners the incentive to increase their supply ahead of the implementation of the Program.[4] The first testable implication that we derive from the green paradox literature, therefore, is that we should observe a fall in the price of coal following the announcement of the 1990 CAAA. Since pricing sulfur makes high-sulfur coal more expensive to burn per unit of electricity than low-sulfur coal, high-sulfur mines have stronger incentives to expand their supply ahead of the upcoming implementation of the cap in January 1995. The second testable implication from the green paradox theory is, therefore, that the price fall should be larger for high-sulfur coal than for low-sulfur coal, i.e. we should observe an increase in the sulfur premium. These two price effects should induce corresponding quantity effects, which make up our third and fourth hypotheses. A reduction of the price of coal would make coal-fired generation more competitive, move coal-burning plants down the merit order, and lead to an increase in coal demand. Thus, the third implication of the theory is that coal-fired utilities would increase their coal input (measured in energy units) over the period 1991–1994. The larger price drop for high-sulfur coal, in turn, should increase the sulfur intensity of the coal purchased by coal-fired utilities in the interim of the regulation, which is our fourth hypothesis. The increased use of coal, and the higher sulfur intensity of the coal burned are clearly unintended, detrimental effects of the announcement of the Acid Rain Program, and hence constitute a green paradox.

Overall, our empirical results provide strong support for the first two hypotheses discussed above. We are able to identify a significant drop in the price of coal (around 9% across a range of different estimates), and a substantial increase in the sulfur premium (roughly 40%). Our conclusions are more qualified for the third hypothesis, as we show that only some plants are found to have increased their heat input. Not surprisingly, given the procurement strategies prevailing in the industry, only plants habitually operating on the spot market were sufficiently flexible to react to the price drop in a significant manner. Finally, we find no evidence that the sulfur intensity of coal increased. Rather, our evidence suggests that crucial institutional arrangements in the industry prevented a shift to dirtier coal. Indeed, we find that firms operating in states where regulators required pre-approval of compliance plans for the new policy may have acted ahead of the ARP implementation, to reduce, rather than increase the sulfur intensity of their coal. Overall, our evidence for the emergence of a green paradox is mixed. Our discussion in the conclusions hints at several reasons why this might have been the case, and is ultimately instructive as to how policy design can mitigate the incentives that might lead to a green paradox.

The rest of the paper is organized as follows. Section 2 gives a brief overview of the literature on the green paradox and explains our choice for the Acid Rain Program and the U.S. coal market as the subject of our empirical analysis. Section 3 provides an overview of the U.S. electricity sector in the 1980s–1990s, together with a discussion of the evolution of SO_2 regulation in the sector, from the 1970 CAAA to Title IV of the 1990 CAAA. Section 4 presents the implications of regulatory

[1] The ARP itself has been the focus of much research, and has been thoroughly evaluated. Overall this research shows that the ARP was very successful in reducing sulfur dioxide emissions at a cost lower than expected. See Ellerman et al. (2000) for an overview.

[2] Although the green paradox hypothesis is usually studied in the context of climate policy, we use the Acid Rain Program as our case study for reasons of data availability, and due to the similarities in both the type of policy and the markets affected. This aspect is discussed at length in Section 2.

[3] This is because the combustion of coal, which contains a variable percentage of sulfur, implies the generation of SO_2 as a by-product. Compliance with a cap on SO_2 emissions can be achieved either by reducing the amount of coal burned, the sulfur content of the coal, or by adopting appropriate abatement technologies, e.g. flue gas desulfurization units (scrubbers).

[4] Note that coal-fired power plants consume more than 90% of all coal mined in the U.S. (U.S. EIA, 2011b).

design for our empirical endeavour as well as our empirical models. We present our results in Section 5. Finally, Section 6 discusses our results in the context of the green paradox literature, and draws conclusions for climate policy.

2. Background to our study

Sinn's (2008) work prompted several authors to study the effects of climate policy on the supply of and the demand for fossil fuels. The literature on the green paradox has identified several ways in which imperfectly designed policies potentially effect an increase in polluting emissions or in (the discounted value of) environmental damages.[5] One of the earliest contributions is Gerlagh (2011), who identifies conditions under which a reduction in the price of a clean substitute would induce either effect, using a simple analytical model. Van der Ploeg and Withagen (2012) and Grafton et al. (2012) also discuss the role of a decrease in the cost of substitutes to fossil energy. Hoel (2011, 2012a), instead, studies the effects of different time profiles of a carbon tax on emissions and damages. Fischer and Salant (2012) resort to a numerical model to compare the effects of alternative climate policies on the intertemporal distribution of carbon dioxide emissions. Eichner and Pethig (2011) construct an analytical two-period three-country model to study how unilateral emission reductions may induce an increase in emissions by non-abating countries, that offsets emission reductions by abating countries. This so-called carbon leakage effect had been extensively studied in static analytical and numerical models of international trade, without resource scarcity, already in the 1990s (see e.g. Bohm, 1993; Felder and Rutherford, 1993; see Burniaux and Oliveira Martins, 2012, for an overview). Finally, the consequences of a time lag between the policy's announcement and its implementation on fuel use and emissions have been studied both in models with (Eichner and Pethig, 2011; Di Maria et al., 2012) and without resource scarcity (Smulders et al., 2012).

As clearly shown by the brief overview in the preceding paragraph, to date no attempt has been made to study the green paradox hypothesis from an empirical perspective. Our goal in this paper is to fill this gap and to use the Acid Rain Program to empirically assess whether a time lag in the implementation of a policy (i.e. a time lag between the instant at which agents become aware of a future policy and the date of its actual implementation) affects resource prices and their use in the way postulated by the green paradox literature.

Our focus on the ARP, rather than some climate policy, as a case study for the green paradox is mostly driven by obvious data availability motivations. There are, however, several reasons, both theoretical and empirical, why our results provide general lessons in the green paradox debate. While it is true that the green paradox literature is generally framed within the context of climate change, it applies to any type of polluting resource and is not restricted to greenhouse gas emissions.[6] Thus, SO_2 policy falls within the relevant range of policies. More importantly, the ARP exhibits strong similarities with the type of climate policy options currently implemented or planned, and can thus be used as a useful acid test for the green paradox hypothesis. First, both climate and SO_2 policies aim to regulate the future consumption of fossil fuels and hence are expected to affect the supply behaviour of coal, oil and gas producers. Second, both types of policies focus on large emitters, markedly on electricity generators. Third, the ARP has been the market-based template upon which most of the existing and planned cap and trade schemes have been modelled (notably the European Union Emissions Trading Scheme, the Regional Greenhouse Gas Initiative, and the Western Climate Initiative). Fourth, the compliance options for the scheme participants are limited, and very similar under both SO_2 and CO_2 regulation: market participants may buy allowances, switch to less polluting fuels[7], or adopt end-of-pipe abatement technologies (flue-gas desulfurization units in the case of SO_2, carbon capture and sequestration units for CO_2). Finally, the lags between announcement and implementation of the ARP – 5 years for the oldest and dirtiest power plants (Phase I plants), 10 years for all other plants (Phase II) – are of the same order of magnitude as the implementation lags for the EU ETS, which was first announced in 2001, had a 'pilot' phase in 2005–2007, and started in 2008 (Ellerman et al., 2010). The insights we derive below from the implementation of the ARP may therefore be useful to policymakers contemplating future climate policies, especially given the pressure on developing countries to start curbing their emissions from 2020 onward.

[5] Van der Werf and Di Maria (2012) offer a thorough review of this literature.

[6] Despite the fact that, as shown by e.g. Smulders et al. (2012), the scarcity of the resource is not crucial to the emergence of a green paradox, the majority of the literature does focus on exhaustible resources. Our study is no exception in this respect, as we study coal. While on the basis of global reserves, coal could be considered as an abundant resource (the world reserve-to-production (R/P) ratio for coal was 235 in 1993 according to the BP Statistical Review of Energy), from a local point of view coal is instead a scarce resource. This is primarily due to its bulky nature and the associated prohibitive transportation costs. To put things in context, the R/P ratio in the U.S. was 28, 22, and 19, in 1986, 1990 and 1995, respectively (U.S. EIA, 1995). This 'spatial scarcity' is emphasized by, for example, Kolstad (1994) and Gaudet et al. (2001). Gaudet et al. (2001), in particular, develop a model in which resource owners and users are spatially distributed and where the user cost of coal consists of extraction costs, transport costs, and other costs related to the quality of the coal delivered, as well as the scarcity rent. Each utility preferentially purchases coal from the mine offering the cheapest coal in terms of its full user cost. Thus, mines with low-cost high-quality coal, located nearby power plants, command higher scarcity rents than mines with an inconvenient location, high extraction costs, or low-quality coal.

[7] Differences in SO_2 contents for different grades of coal can be large, while Quick (2010) reports differences in CO_2 emission factors across coal types in excess of 10%.

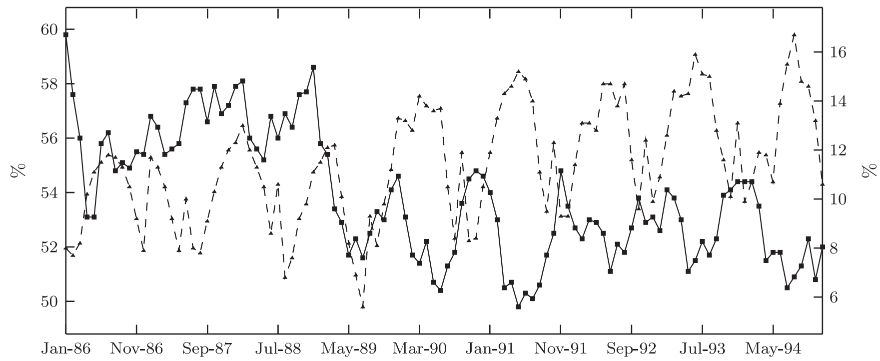

Fig. 1. Shares of electricity produced using Coal (solid line, left axis) and Natural Gas (dashed line, right axis) as percentages of total U.S. electricity generation, 1987–1994. Source: U.S. EIA (2010).

3. Coal-fired electricity generation in the U.S., and the SO_2 trading program

Historically, coal-fired power plants have supplied more than 50% of all electricity used in the United States (U.S. EIA, 2010). Due to the oil price increases of the mid-1970s, coal-fired generation capacity increased throughout the 1980s. Since 1990, however, significant amounts of gas-fired generation have been added, raising the share of gas to around 15% of total generation capacity (U.S. EIA, 2011a), see Fig. 1.

Throughout the period covered by our analysis, power plants were economically regulated by the state they were located in, generally with a rate of return regulation so that each plant's output price was set as some fraction above its costs of production. Plants faced the obligation to meet the state's electricity demand, and thus had less choice over how much and when to produce than would be the case in a liberalized electricity market. This requirement to produce implied that plants were very concerned with assuring a steady supply of fuel. This concern was heightened for coal-fired power plants as they are often base-load plants in an electricity system. Base-load plants are utilized as close as possible to full capacity at all hours of the day, because of their low marginal cost of production and the higher costs to stop and re-start. Nuclear power plants also tend to represent the base-load of the system, while the more flexible natural gas plants tend to be used at peak demand times.

The concern over fuel supply meant that a large majority of coal transactions occurred under long-term forward contracts between plants and coal mines. The contracts were quite complex with many provisions to protect against the ‘hold-up’ problem. Joskow (1985, 1990) has shown that these contracts were largely adhered to even in the face of changes in the spot market coal price, and regulation. The average duration of contracts was about 10 years throughout the 1980s and 1990s, though it was decreasing over time (Lange and Bellas, 2007). The decreased duration was accompanied by an increase in spot market transactions from 10% to 20% of all transactions. The largest increase in spot market activity came from the Western coal region (Kozhevnikova and Lange, 2009). Several commentators have attributed this to the railroad deregulation that began in the mid-1980s: the real prices for shipping coal by rail fell considerably in the late-1980s and 1990s, making Western coal more attractive to utilities in the Mid-West (Ellerman and Montero, 1998; Gerking and Hamilton, 2008). The emergence of a significant spot market in the late 1980s allows us to identify the impact of the introduction of the ARP on coal (spot) market prices and quantities delivered, which would otherwise be very sluggish in the presence of long run contracts. For this reason, we focus our analysis on the period after 1985, when the spot market became deep enough for the price to be considered a meaningful indicator of scarcity (Kozhevnikova and Lange, 2009).

Coal-fired power plants were not only regulated for economic reasons, but also for environmental reasons, as the burning of coal causes the emission of atmospheric pollutants such as SO_2. U.S. federal regulation of SO_2 emissions from coal-fired plants began with the 1970 CAAA, under which a vintage-differentiated emission standard was employed. New plants were subject to the New Source Performance Standards (NSPS), known as NSPS-D, a federal emissions standard of 1.2 pounds of SO_2 per million Btu (lbs/MBtu). The 1977 CAAA tightened restrictions on new plants by expanding the NSPS (known as NSPS-Da) to add a requirement to remove 70–90% of SO_2 post-combustion. The introduction of the NSPS induced owners of power plants to extend the lifetime of existing boilers and resulted in a slower reduction in SO_2 emissions than policymakers had hoped for (Nelson et al., 1993; Stavins, 2006). To fill this gap in the regulation, the Bush Administration introduced provisions to regulate SO_2 emissions via a ‘cap and trade’ program in the summer of 1989. The proposal went through the necessary steps of legislation between 1989 and 1990, being finally signed into law by President G.H.W. Bush on November 15, 1990.

The provisions contained in Title IV of the 1990 CAAA introduced emissions trading in two phases. During Phase I, starting on January 1, 1995, the older, still unregulated boilers were brought under federal regulation. Starting from January 1995, 263 generating units with an emission rate larger than or equal to 2.5 lbs/MBtu in 1985 were granted emission allowances of about 2.5 lbs/MBtu at baseline 1985–1987 fuel use (Ellerman et al., 2000). Each emission allowance would allow its holder to emit one ton of SO_2 in the year of issue or any subsequent year. Phase II, starting on January 1, 2000, covered all units with a capacity of at least 25 MW. Phase II units were to receive allowances at an emission rate of 1.2 lbs/

MBtu. The ARP required firms to deliver valid allowances to the U.S. Environmental Protection Agency within thirty days following the end of the calendar year.

The history of SO_2 regulation in the U.S. and the design of the ARP allow us to exploit regulatory differences across U.S. coal-fired power plants to identify the effects of the announcement of the 1990 CAAA on Phase I plants. These plants had been previously unregulated at the federal level, and were generally emitting sulfur dioxide at a much higher rate than other plants. Emissions standards that applied to them at the state level were generous and usually non-binding (Ackerman and Hassler, 1981). NSPS plants, on the contrary, were subject to regulations set down in earlier versions of the CAAA. These plants were federally regulated either by an emissions standard or an emissions standard and an implicit technology standard. Given that NSPS plants were subject to binding emissions or technology standards, these plants were – contrary to Phase I plants – unable to respond to lower coal prices through an increase in emissions. This setting makes it possible to treat the announcement of the ARP as exogenous. As we discuss below, by framing Phase I plants as the treatment group and NSPS plants as the control one, we are able to tease out useful information using a difference-in-difference estimation on the impact of the ARP on coal use, and to shed light on the emergence of a green paradox.

4. Empirical strategy

The aim of the present paper is to assess the green paradox hypothesis empirically. More specifically, our goal is to verify whether the passing into law of the 1990 CAAA effected changes in the behaviour of coal suppliers and users that are consistent with the theoretical predictions of the green paradox literature.

According to the theory, a green paradox emerges when, following the announcement of a policy aimed at curtailing the demand for fossil fuels, resource owners perceive a threat to their future profitability and modify their supply decisions to sell more fuels in the nearer future. As a consequence of this supply shift, the market price for the resource falls following the announcement of the policy. In the context of our case study of the U.S. coal industry in the 1990s, this leads us to formulate the following testable hypothesis that we can take to the data:

Hypothesis 1. Following the passing into law of the 1990 CAAA, the (spot) price of coal decreased.

Coal, moreover, is not a homogeneous commodity as it is available in a variety of grades with different carbon, sulfur, moisture, ash, and volatile matter contents. This implies, from a theoretical perspective, that regulating sulfur emissions has consequences for the relative desirability of different types of coal. One would indeed expect that cleaner varieties become more desirable, increasing the price penalty for high-sulfur coal. In the presence of an announced cap on emissions, the price of dirtier, high-sulfur coal should drop more than the price of cleaner, low-sulfur coal.[8] The following hypothesis follows directly from this discussion:

Hypothesis 2. Following the passing into law of the 1990 CAAA, the sulfur premium increased.

The existence of a green paradox ought to be observable, besides through changes in prices, in changes in the quantity of coal being used in electricity generation. Indeed, as coal gets cheaper (Hypothesis 1), power plants may be able to move down the merit order and dispatch more electricity, thus requiring additional inputs. Hence, we get:

Hypothesis 3. Following the passing into law of the 1990 CAAA, the quantity of coal purchased by Phase I power plants increased, relatively to other plants.

Finally, since high-sulfur coal becomes more attractive for energy generators due to the increased sulfur premium discussed above, we would expect to observe a shift in the composition of purchases towards coal with higher sulfur content per unit of energy. Our final hypothesis is, then:

Hypothesis 4. Following the passing into law of the 1990 CAAA, the sulfur intensity of the coal purchased by Phase I power plants increased, relatively to other plants.

To test the first two hypotheses, that is, to verify whether the price of coal fell after the announcement of the ARP, and the sulfur premium increased, we resort to a hedonic price regression similar to those commonly used in the literature (see e.g. Joskow, 1990; Keohane and Busse, 2007; Lange and Bellas, 2007). Our model is

$$p_{j,t} = \alpha_{0,j} + \alpha_{1,n} + \alpha_2 \,\text{Sulfur}_{j,t} + \alpha_3 \,\text{Sulfur}_{j,t} \times \text{Interim}_t + \mathbf{x}'_{j,t}\boldsymbol{\alpha} + \varepsilon_{j,t}. \tag{1}$$

We estimate Eq. (1) using data for the period 1986–1994. Appendix A describes the data and provides both the sources of the data and the summary statistics for all variables. The dependent variable is the weighted average real price (per million Btu) of coal delivered to plant j in month t, for deliveries agreed upon on the spot market. As Joskow (1988, 1990) discusses, contract prices do not respond to market conditions as quickly as spot prices due to the price adjustment mechanism in the contract. As a result, this analysis is undertaken for spot market transactions. Both plant and year fixed effects are accounted for, and are represented by $\alpha_{0,j}$ and $\alpha_{1,n}$, respectively. The year fixed effects will determine whether prices fell in conjunction

[8] Di Maria et al. (2012) provide a thorough theoretical treatment of these effects in the context of a model of exhaustible resource extraction à la Hotelling (1931), extended to allow for the presence of multiple resources that differ in pollution intensity.

with the announcement of the ARP (Hypothesis 1). $\text{Sulfur}_{j,t}$ is the weighted average sulfur content of deliveries to plant j in month t and Interim_t is a dummy that has a value equal to one in the period December 1990–December 1994 and zero otherwise.[9] Coefficient α_3 will reveal whether the discount for high-sulfur coal increased after the passage of the 1990 CAAA (Hypothesis 2). The vector $\mathbf{x}_{j,t}$ indicates a vector of control variables. It includes the heat and ash content of the coal as well as its region of origin to control for the characteristics of the coal delivered. We construct a proxy for transportation costs to control for both transport distance and falling rail transport costs (Ellerman and Montero, 1998; Gerking and Hamilton, 2008). We control for mining productivity developments east and west of the Mississippi to take into account the significant productivity improvements over time as well as their spatial differences (Stoker et al., 2005). We include the real natural gas price to control for competition between fuels. Finally, ε is an IID error term.

Our third hypothesis states that mandatory Phase I plants should increase the amount of heat consumed after announcement of the ARP. A difference-in-difference methodology is utilized as it can distinguish between changes that are due to the announcement of the 1990 CAAA and general trends in the industry. The regulatory setting makes it possible to assign plants to a treatment (Phase I) and a control (Phase II) to facilitate the difference-in-difference analysis. For this and the fourth hypothesis, we follow in principle the research design of Greenstone et al. (2010) in that we first use a difference-in-difference estimator, and then expand upon the results with triple-difference estimators. Thus, our first step is to estimate a model which shows how the pre-and post-announcement trends evolve. Following this, further specifications are introduced to check for the robustness of our results. The pre- and post-announcement trends model is

$$h_{j,t} = \beta_{0,j} + \beta_{1,n}\delta_n + \beta_{2,n}\delta_n \times \text{PhaseI}_j + \mathbf{x}'_{j,t}\boldsymbol{\beta} + \eta_{j,t}. \tag{2}$$

The dependent variable is the natural log of billion Btu purchased by plant j in month t. Both plant- and year-fixed effects are accounted for, and are represented by $\beta_{0,j}$ and $\beta_{1,n}$, respectively. Our difference-in-difference parameters are year dummies interacted with a dummy that is equal to one for mandatory Phase I plants and zero otherwise: $\delta_n \times \text{PhaseI}_j$. Plants that contain at least one boiler that was mandated to be part of Phase I are the treatment group with different subsets of non-Phase I plants as control groups. The vector $\mathbf{x}_{j,t}$ indicates a vector of control variables, consisting of an index for state-level economic activity, a dummy equal to one for plants that have a scrubber installed, summer and winter dummies, and the real natural gas price. Finally, $\eta_{j,t}$ is an IID error term.

In order for $\beta_{2,n}$ to be a consistent estimate of the impact of the ARP announcement on heat input (and sulfur intensity, as discussed below) in our difference-in-difference analysis, two assumptions should be met. The first is that assignment to treatment (Phase I) and control (Phase II) for plants is not influenced by their heat input or sulfur intensity. We contend that, given the nature of the pre-existing regulation, the existence of two regulatory vintage groups of power plants allows for exogeneity of the treatment. Second, the pre-announcement trends in heat input or sulfur intensity for the two groups should not suggest that other factors were encouraging different behavior before the announcement of the ARP.[10] If the coefficients for $\beta_{2,n}$ for the years before the announcement of the ARP are not statistically different from zero, this would support the assumption that pre-announcement factors are the same for the treatment and control plants and that no changes in behavior are being falsely attributed to the announcement of the ARP. Positive and statistically significant coefficients of the post-announcement interaction terms, instead, would support the green paradox hypothesis, as they signify that mandatory Phase I plants increased their heat consumption relative to the control group's consumption. These results are discussed below. While the general difference-in-difference estimation in Eq. (2) helps reveal the validity of the empirical model, other factors may alter how mandatory Phase I plants respond to the 1990 CAAA passage, relative to the control group. To explore whether regulatory or market factors are confounding our analysis, a triple difference-in-difference model is estimated. The triple difference model is

$$h_{j,t} = \gamma_{0,j} + \gamma_{1,n} + \gamma_2 \,\text{Interim}_t + \gamma_3 \,\text{Interim}_t \times \text{PhaseI}_j + \gamma_4 \,\text{Interim}_t \times \text{PhaseI}_j \times \text{Triple}_j + \mathbf{x}'_{j,t}\boldsymbol{\gamma} + \nu_{j,t}. \tag{3}$$

The interaction of the ‘Phase I’ and ‘Interim’ dummy variables is the first difference-in-differences variable: if γ_3 is positive and significant, Phase I plants purchased more heat after announcement, relative to non-Phase I plants. Here, however, the focus is on three possible factors that may have affected the ability of Phase I plants to take advantage of the cheaper coal. First, we are interested in assessing the impact of rigidities in coal procurement, and ask to what extent Phase I plants were constrained by existing long-term contracts on the coal market. Our first ‘Triple’ variable is thus ‘High Spot’, a dummy that identifies plants that purchase a large share of their coal on the spot market, rather than rely on long-term contracts. We expect that plants with a higher degree of exposure to the spot market would be able to buy more coal at lower prices during the interim phase, implying a positive estimate for γ_4. Second, we concentrate on plants that operate in states where no nuclear plants are operating. The presence of nuclear stations makes it more difficult for coal-fired generators to expand their production since nuclear generation is typically cheaper and has higher start-up costs. Thus, when ‘Triple’ is ‘No-nuclear’, we expect a positive estimate for the γ_4 coefficient. Finally, we consider whether the fact that some plants were

[9] Various dates can be picked as the announcement date. The announcement of the clean air proposal in the summer of 1989 and the signing into law of the CAAA in November 1990 appear to be most relevant. In addition, the question is how fast spot prices were able to respond to these announcements. To be general, we therefore use year (interaction) dummies in our core regressions throughout the paper, where it can be checked whether prices or quantities changed in 1989 or 1990. Our ‘Interim period’ dummy variable is equal to one for months after November 1990.

[10] If the pre-announcement data on heat input and sulfur intensity were converging or diverging, then the difference-in-difference estimation would attribute the continuation of this pattern to the announcement, when in fact the announcement has not altered behaviour.

required by their state-level Public Utility Commission (PUC) to submit a compliance plan before the start of Phase I might have limited their ability to increase production. Indeed, if plants had to undergo additional maintenance or install new machinery, for example, to ensure that their plan would function as expected, we might expect a negative estimate for γ_4 when 'Triple' is 'Pre-approval'.

We test our fourth and final hypothesis, which states that the sulfur content of coal used increased after announcement, using a difference-in-difference analysis, similar to Eq. (2). The model, which has as dependent variable the SO_2 intensity (in lbs/MBtu) of the coal delivered to the power plants, is

$$i_{j,t} = \mu_{0,j} + \mu_{1,n}\delta_n + \mu_{2,n}\delta_n \times \mathrm{PhaseI}_j + \mathbf{x}'_{j,t}\boldsymbol{\mu} + \zeta_{j,t}. \tag{4}$$

Again this will show how the pre- and post-announcement trends evolve for Phase I plants and with different subsets of non-Phase I plants as control groups. Our set of control variables for the sulfur content of coal includes a scrubber dummy, rail transportation costs per ton-mile interacted with a dummy equal to one for plants located in a relevant range from the Powder River coal Basin (PRB), and controls for the region of origin of the coal. The region of origin is relevant for sulfur content as coal from the PRB has the lowest sulfur content of the three main regions, while coal from the Interior region has the highest sulfur content and the Appalachian region is in between the other two. In addition, Ellerman and Montero (1998) show that the declining rail transport prices in the 1980s and 1990s changed the economics of coal choice in favor of the coal from the PRB for power plants in a range of 400–1200 miles from the PRB.

To test whether other factors influence the decision of power plants to buy low-sulfur coal, we use a triple difference-in-difference model similar to Eq. (3). For Hypothesis 4, however, 'Triple' controls for whether the state the Phase I plant is located in has strict environmental standards, or whether the plant was required to submit a compliance plan before the start of the ARP. Our prior for both controls is that plants facing stringent state regulation or that are required to obtain pre-approval of their compliance plans would find it difficult to switch to dirtier coal (Lile and Burtraw, 1998). As a consequence, we would expect a negative coefficient for the triple difference-in-difference coefficients.

5. Results

Table 1 shows the results of our estimations of Eq. (1), which refers to the hypothesis that coal prices fell after announcement of the 1990 CAAA. In the interest of brevity, we suppress the results for the coefficients for additional control variables in the tables presented in the main text, these additional coefficients are reported in Appendix B. In column (1) we present results for all spot transactions, in column (2) we focus on transactions on the spot market by plants located in states with Phase I plants. Both regressions reveal that coal prices were lower during the period 1990–1992 by about 14 cents per MBtu, accounting for a drop of 9% relative to the price during the previous three years (1987–1989).[11] This suggests that the announcement of the 1990 CAAA might indeed have had an impact such as the one suggested by Hypothesis 1.[12] The price recovery in 1993–1994 revealed by our regressions might instead be linked to supply disruptions, following the 7-month United Mine Workers' strike in the second half of 1993. As expected, high-sulfur coal is traded at lower prices than low-sulfur coal. The coefficient for the interaction term of sulfur content and a dummy for the period after announcement show that the sulfur premium increased significantly (by about 40%), after it became clear that high-sulfur coal would become harder to sell in the future. This confirms Hypothesis 2. The control variables, listed in Table B.1, generally follow expectations. Higher miner productivity leads to a lower price, Western Basin coal is cheaper than Appalachian Basin coal (Western Basin coal is generally surface-mined while Appalachian Basin coal is often from underground mines) and higher gas prices lead to higher coal prices (as they are substitutes).

Overall, this evidence supports our first two hypotheses, namely that the announcement of the cap on SO_2 emissions appears to have had a depressing effect on coal prices, and a stronger one for high-sulfur coal.[13]

Next, we ask whether these lower coal prices in the interim of the ARP affected the amount of coal burned by U.S. power plants.[14] Specifically, we investigate whether coal-fired generators increased their heat input after the announcement of the 1990 CAAA (Hypothesis 3). Table 2 shows the results of a panel estimation of Eq. (2), focusing on the pre- and post-announcement trends. Column (1) uses the whole sample of non-Phase I power plants as the control group. Our

[11] The t-test for the difference between the average of the year-fixed effects for 1987–1989 and the average for 1990–1992 shows a statistically significant price difference of 14 cents per MBtu after announcement (t-stat$=$6.81).

[12] These results correlate to the finding of Kahn and Knittel (2003) that the unveiling of the proposed amendments to the Clean Air Act by President Bush in June of 1989 had a negative impact on coal mining company's stock prices.

[13] Our evidence is consistent with the alternative interpretation of the price drop having been determined by a decrease in demand, rather than by an increase in supply. However, Fig. 1 indicates that the share of electricity generated using coal has been rather stable over the period 1989–1994. Given the steady increase in overall electricity demand over the same period, this seems to point to an increase rather than a decrease in the demand for coal. Furthermore, Fig. 2 emphasizes that the level of heat input demanded by power plants has been unchanged over the period we analyze, a conclusion that we support statistically below. Since we do not observe any closures of coal-fired power plants between 1989 and 1994 in our sample, this further supports our conclusion that the drop in price was not driven by demand side effects. For completeness, we estimated a supply function for coal, by regressing the real cost of coal on quantity, productivity level, transportation costs and dummies for the region of origin of the coal, using the coincident activity index and the real price of natural gas as instruments for demand shifts. Using these supply estimates, we identify a price drop of 13.8 cents, which confirms our previous results. Full details are available from the authors upon request.

[14] To control for possible State-level serial correlation, we follow Bertrand et al. (2004) and compute standard errors clustered by State.

Table 1
Hedonic coal price regressions.

Dependent variable	Weighted average real price[a]	
	(1)	(2)
Sample	Spot transactions	Spot transactions for plants in states with Phase I plants
	Coefficient (S.E.)	Coefficient (S.E.)
1987	−28.26***	−27.80***
	(1.28)	(1.31)
1988	−11.55***	−11.39***
	(1.87)	(1.94)
1989	−30.17***	−30.51***
	(2.62)	(2.55)
1990	−40.31***	−39.17***
	(3.39)	(3.77)
1991	−35.36***	−34.49***
	(3.42)	(4.11)
1992	−37.49***	−37.68***
	(3.52)	(4.24)
1993	−27.13***	−26.51***
	(3.69)	(4.27)
1994	−16.87***	−17.13***
	(3.85)	(4.32)
Sulfur content	−3.57***	−3.50***
	(0.93)	(0.94)
Sulfur content × interim period	−1.43***	−1.36**
	(0.52)	(0.60)
Observations	19 863	15 799
Plants	367	276

Additional controls for all regressions are Coal Region Share, Real Transport Costs, Real Natural Gas Price, Ash Content, Heat Content, and Plant Dummies. Standard errors corrected for panel serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.
[a] Average delivery price, weighted by heat-content for each plant, month.

estimates reveal that using this control group is not appropriate, as its pre-announcement trends are different from those of mandatory Phase I plants (the treatment group). This outcome is not surprising as a number of papers have shown that spatial variation is important in the coal market. Almost all mandatory Phase I plants are located east of the Mississippi River, while the low-sulfur coal mining region PRB is located west of the Mississippi. Keohane and Busse (2007) show that railroad firms price-discriminated based on plants' proximity to the PRB. Joskow (1987) finds that the contract duration is dependent on which coal region the mine is located in (Appalachian, Interior, or Western). Ellerman and Montero (1998), Gerking and Hamilton (2008) and Kozhevnikova and Lange (2009) all find differences in plants' decision-making by their geographic location.

In order to provide a better control group, the other three columns restrict the sample of non-Phase I plants to those in states with mandatory Phase I plants. Column (2) shows the results of our second regression model, when the control group is represented by non-Phase I plants operating in states that have at least one Phase I plant. Besides the economic rationale previously discussed, the regression results suggest that the choice for this control group is consistent with a proper research design. Indeed, the pre-announcement trend is not statistically different from that of the mandatory Phase I plants. Obviously, the use of these plants as our control group is only justifiable if we can be sure that the announcement of the ARP did not affect non-Phase I plants the way it might have affected Phase I plants. Fig. 2 shows the average heat input per month for both mandatory Phase I plants and non-Phase I plants in states with Phase I plants. The average heat input for the control group does not exhibit any break following the announcement of the change in legislation. This visual impression is confirmed by a statistical test on the equality of the coefficients of the year dummies over the 1989–1991 period.[15]

The post-announcement interaction variables in column (2) are all statistically insignificant, suggesting that Phase I plants did not increase their heat input relative to the control group. Thus, despite the fall in coal prices documented above, our analysis so far fails to identify any quantity response to the announcement of the ARP.

As a robustness check, column (3) of Table 2 shows the results obtained when the control group is further restricted to only include NSPS-Da plants in states with Phase I plants. NSPS-Da plants are essentially required to have a scrubber in

[15] The F-test statistic for the joint hypothesis test equals 1.46, with a p-value of 0.26. We also perform a test for the stability of the slope parameters in the period before and after the policy announcement, and we fail to reject the null that the parameters are indeed stable. The complete results are available from the authors upon request.

Table 2
Heat input hypothesis.

Dependent variable	Natural log of total heat purchased			
Sample	All transactions	All transactions for plants in states with Phase I plants	All transactions for Phase I plants or NSPS-Da plants in states with Phase I plants	All Transactions for Phase I Plants or high-utilization NSPS-Da Plants in States with Phase I Plants
	(1) Coefficient (S.E.)	(2) Coefficient (S.E.)	(3) Coefficient (S.E.)	(4) Coefficient (S.E)
1987 × Phase I	−0.02	−0.02	−0.02	−0.01
	(0.03)	(0.03)	(0.04)	(0.03)
1988 × Phase I	−0.07**	−0.05	−0.03	−0.01
	(0.04)	(0.04)	(0.05)	(0.04)
1989 × Phase I	−0.09**	−0.04	−0.03	−0.02
	(0.05)	(0.06)	(0.07)	(0.06)
1990 × Phase I	−0.03	0.01	0.04	0.02
	(0.04)	(0.05)	(0.06)	(0.06)
1991 × Phase I	−0.06	−0.01	0.03	0.01
	(0.05)	(0.06)	(0.06)	(0.07)
1992 × Phase I	−0.05	0.03	0.06	0.03
	(0.05)	(0.06)	(0.07)	(0.06)
1993 × Phase I	−0.17***	−0.07	−0.05	−0.02
	(0.06)	(0.06)	(0.06)	(0.05)
1994 × Phase I	−0.16***	−0.09	−0.05	−0.02
	(0.06)	(0.06)	(0.07)	(0.06)
Observations	38 315	27 190	22 314	19 395
Plants	401	288	237	223

Controls for all regressions are State GDP, Scrubber Dummy, Real Natural Gas Price, Summer, Winter, Year and plant dummies.
Standard errors corrected for panel serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1987–1994.

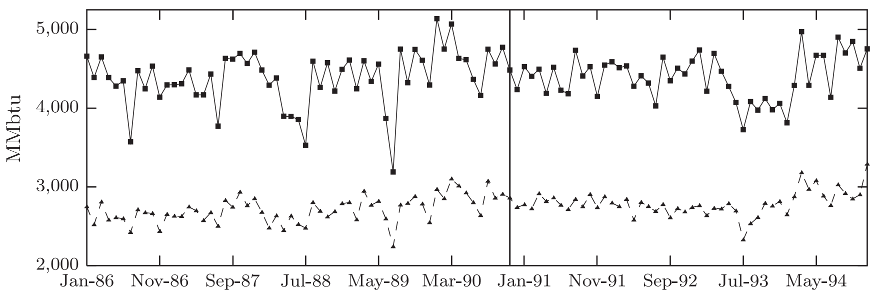

Fig. 2. Average heat input per month for Phase I plants (solid line) and for non-Phase I plants in States with Phase I plants (dashed line). Source: Authors' calculations using FERC 423 data.

addition to an emissions standard, thus the announcement of the ARP does not increase the stringency of the regulation for these plants. The statistically insignificant difference in the pre-announcement trends suggests that such plants also constitute an appropriate control group. Also in this case, the post-announcement interaction variables are all statistically insignificant, providing further evidence that the treated group did not behave differently from the control group. In the interest of completeness, in column (4) we report the results of an additional regression, this time estimated using as control group those NSPS-Da plants, in states with Phase I plants, that exhibit a high degree of capacity utilization.[16] Once again, the regression results are qualitatively unchanged, and we do not find evidence in support of Hypothesis 3. The control variables are generally consistent across the four estimations. State GDP, gas prices and Summer months are all positively correlated with heat purchased.

From our discussion so far, it appears that the announcement of the ARP did not have any significant impact on coal consumption. It is possible, however, that specific factors have restricted the power plants' ability to change their behaviour in response to the announcement of the ARP. As mentioned in Section 4, we focus on three such factors here. We start by

[16] The control group is constructed by eliminating from the group of NSPS-Da plants in states with Phase I plants any plant that is recorded as having been under load less than 50% of time according to data given in the EIA-Form 767 (U.S. EIA, 2006).

Table 3
Heat input hypothesis, additional results.

Dependent variable	Natural log of total heat purchased					
Sample	(1) All transactions for plants for states with Phase I plants Coefficient (S.E.)	(2) All transactions for Phase I or NSPS-Da plants in states with Phase I plants Coefficient (S.E.)	(3) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(4) All transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(5) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(6) All transactions for plants in states with Phase I plants Coefficient (S.E.)
Interim period	−0.02 (0.03)	−0.02 (0.04)	−0.03 (0.03)	−0.03 (0.04)	−0.03 (0.04)	−0.05 (0.05)
Interim × Phase I	−0.05 (0.04)	−0.04 (0.04)	−0.04 (0.04)	−0.03 (0.03)	−0.03 (0.04)	−0.00 (0.04)
Interim × Phase I × High-Spot	0.13*** (0.04)	0.16*** (0.05)				
Interim × Phase I × No-Nuclear			0.09 (0.12)	0.17 (0.14)		
Interim × Phase I × Compl. pre-approval					0.04 (0.07)	0.02 (0.05)
Observations	27 190	22 314	27 190	22 314	27 190	22 314
Plants	288	237	288	237	288	237

Controls for all regressions are State GDP, Scrubber Dummy, Real Natural Gas Price, Summer, Winter, Year and Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

considering the possibility that plants that obtain a large share of their coal based on pre-existing long-term contracts are unlikely to be able to benefit from cheaper coal on the spot market. Similarly, we suggest that plants facing the competition of nuclear power stations in providing cheap energy to cover base-load demand might be less able to expand output, despite the availability of cheaper coal. Finally, it is plausible that plants that operate in states whose PUCs require the pre-approval of detailed compliance plans, would tend to focus on achieving compliance on their own rather than relying on purchasing permits from the market (see e.g. Rose, 1997). This would make them more reluctant to expand output and switch to more polluting coal, and instead would lead them to behave more conservatively. Table 3 shows the results of our triple difference-in-difference analyses.

The results in Table 3 suggest that the institutional structure of the industry, in terms of the prevailing procurement strategies, may play a key role in determining the emergence of a green paradox. First of all, we do find that mandatory Phase I plants that use the spot market for a large share of their coal purchases have indeed increased their heat input in the period between the signing into law of the 1990 CAAA and the start of the ARP in January 1995.[17] The results in columns (1) and (2) provide evidence in support of the existence of a green paradox for this particular subgroup of mandatory Phase I plants. For high-spot plants, the triple difference-in-difference coefficient reveals that, on average, plants in this group increased the sulfur intensity of coal purchased by 13–16%.[18] We fail to find any differential effect of the announcement in terms of heat input for plants operating in states without nuclear power stations, and in states that required the pre-approval of firms' compliance plans.[19]

Taken together, the results from Tables 2 and 3 suggest, quite intuitively, that the likelihood of the emergence of a green paradox is reduced when plants rely more heavily on long-term contracts for their fuel supply. Indeed, plants that make only a minimal use of the spot market would naturally be much less likely to be able to benefit from favourable fluctuations in the coal price.

The fourth testable hypothesis we derive from the green paradox literature states that, as the sulfur premium increases after the announcement of the ARP, more of the – now relatively cheaper – high-sulfur coal would be used by Phase I plants, in the interim of the regulation. Table 4 presents the results of the estimation of Eq. (4), testing the hypothesis that the sulfur content of coal did in fact increase after announcement of the future cap on SO_2 emissions. As argued in Section 3, non-Phase I plants already faced multiple regulations in terms of their SO_2 emissions, thus it is difficult to imagine that they

[17] The 'High-Spot' dummy used in the regressions in Table 3 assumes the value 1 for all years in which a plant received more than 40% of its coal deliveries from spot market contracts. To check the robustness of our results, we first lowered the threshold to 30%, and then increased it to 50%. Moreover, we focussed on the share of deliveries over the entire period, using the same threshold levels. Finally, we experimented designating 'High-Spot' plants only those whose spot share was higher than 40% (30%, 50%) in every year of our sample. In all cases the results were qualitatively very similar.

[18] This increase corresponds to between 19 000 and 24 000 tons of additional SO_2 emissions.

[19] In the interest of brevity, we do not report here the results relative to the high-utilization NSPS-Da plants. Also in this case, however, the results are qualitatively identical to those presented in Table 3, and are available from the authors upon request.

Table 4
Intensity hypothesis.

Dependent variable	Sulfur intensity (SO_2 lbs/MBtu)			
Sample	(1) Spot transactions Coefficient (S.E.)	(2) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(3) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(4) All transactions Coefficient (S.E.)
1987 × Phase I	−0.07	−0.10	−0.09	−0.07
	(0.08)	(0.08)	(0.09)	(0.06)
1988 × Phase I	−0.04	−0.05	−0.4	−0.11
	(0.11)	(0.12)	(0.13)	(0.07)
1989 × Phase I	0.06	0.03	0.06	−0.09
	(0.11)	(0.11)	(0.12)	(0.07)
1990 × Phase I	−0.02	−0.05	−0.07	−0.06
	(0.12)	(0.13)	(0.12)	(0.10)
1991 × Phase I	−0.16*	−0.15*	−0.17*	−0.13
	(0.09)	(0.08)	(0.09)	(0.11)
1992 × Phase I	−0.18**	−0.19**	−0.16*	−0.10
	(0.07)	(0.08)	(0.08)	(0.12)
1993 × Phase I	−0.17**	−0.17*	−0.10	−0.23**
	(0.08)	(0.09)	(0.09)	(0.10)
1994 × Phase I	−0.22**	−0.21*	−0.14	−0.33***
	(0.11)	(0.11)	(0.11)	(0.12)
Observations	20 563	16 396	13 804	40 766
Plants	369	277	228	409

Controls for all regressions are Coal Region Share, Scrubber Dummy; Rail Price, near Powder River Basin, Year and Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

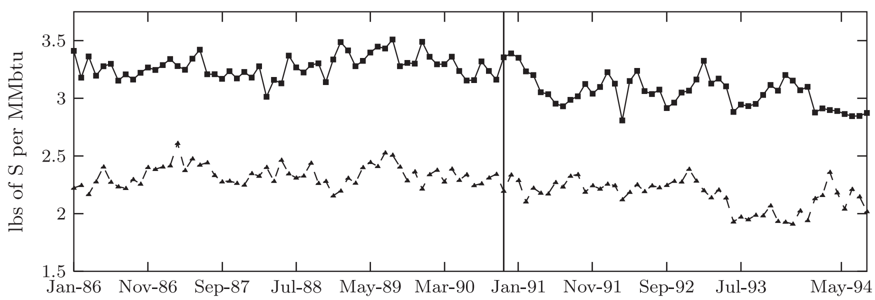

Fig. 3. Average monthly sulfur intensity for Phase I plants (solid line) and for non-Phase I plants in States with Phase I plants (dashed line). Source: Authors' calculations using FERC 423 data.

would react to the increase in the sulfur premium by switching to dirtier coal and increase their emissions intensity. Our priors that non-Phase I plants constitute a good control are supported by the results in Table 4, which show that the pre-treatment trends are not significantly different across the treated and the control group. Moreover, Fig. 3 illustrates that the trend in emissions intensity of the control group did not change as a result of the announcement of the ARP.

The first three columns of Table 4 focus only on deliveries from spot market contracts, since we expect it to be more likely to observe changes in sulfur content for these transactions, relative to deliveries based on long-term contracts. Indeed, we are able to identify changes in the spot data long before any change emerges from the full transactions sample. The changes we identify, however, go in the opposite direction to what is suggested by Hypothesis 4. The negative and significant coefficients we estimate for the regressions in columns (1)–(3) of Table 4, seem rather to suggest that Phase I plants were actively gearing up to comply with the regulation as early as 1991, possibly experimenting with different types of fuel. Using data on all transactions – see column (4) – reveals that overall mandatory Phase I plants decreased their sulfur intensity relative to non-Phase I plants starting from 1993. This is line with the evidence suggesting that several Phase I plants aggressively renegotiated their long-term contracts in anticipation of the commencement of the ARP, with the aim of reducing the sulfur-content of the coal they would receive in the future (Kosnik and Lange, 2011). The control variables show

Table 5
Intensity hypothesis: additional results.

Dependent variable	Sulfur intensity (SO_2 lbs/MBtu)			
Sample	(1) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(2) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(3) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(4) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)
Interim period	0.05 (0.06)	0.05 (0.06)	0.08 (0.06)	0.04 (0.06)
Interim × Phase I	−0.09 (0.06)	−0.07 (0.07)	−0.16** (0.07)	−0.11 (0.07)
Interim × Phase I × pre-approval	−0.26*** (0.07)	−0.15** (0.07)		
Interim × Phase I × Strict State SO_2			0.09 (0.10)	0.02 (0.10)
Observations	16 396	13 804	16 396	13 804
Plants	277	228	277	228

Controls for all regressions are Coal Region Share, Scrubber Dummy; Rail Price, near Powder River Basin, Year and Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

that Western Basin coal has statistically significant lower sulfur content than Appalachian Basin coal while the sulfur content of Interior Basin coal is higher, as expected.

Also in this case the triple difference-in-difference method allows us to control for potential differences amongst mandatory Phase I plants. Here we focus on the possible differential behaviour by plants that were required to submit compliance plans for pre-approval to their PUC. Columns (1) and (2) of Table 5 show the results of this analysis. Neither the regression using all plants in states with Phase I plants, nor the one using the sample restricted to only NSPS-Da plants as control, show any increase in the sulfur intensity for mandatory Phase I plants. As expected, however, the compliance plan requirement seems to have induced reductions in the sulfur intensity of coal inputs by mandatory Phase I plants, already in the interim phase.[20] This is consistent with the view that utilities subject to such scrutiny would tread more cautiously, and make sure of compliance well ahead of time. Column (3) shows that, once we isolate plants operating in states with existing stringent SO_2 regulation, other Phase I plants can be seen to reduce their sulfur intensity. Once more, this is consistent with early action on the part of previously unregulated Phase I plants to prepare to comply with the requirements of the ARP. We interpret these results as further evidence that the institutional setting in which power plants operate is one of the key determinants of their behaviour.

6. Concluding remarks

A series of recent contributions in the literature on suboptimal climate policy has identified several mechanisms through which such a policy could theoretically lead to detrimental environmental outcomes (a 'green paradox'). One of such mechanisms is through the response of suppliers of nonrenewable resources in the presence of an implementation lag for the policy. In this paper we have taken the first step to empirically assess this theory.

We have argued that the implementation lag that characterized the SO_2 cap and trade program under the 1990 CAAA has strong parallels with implementation lags in climate policy. We have presented four testable implications regarding the effects of the announcement of the cap. The first hypothesis states that the price of coal would fall after the announcement, as resource owners see the prospects of future sales decline; moreover, this effect should be stronger for poorer quality (in terms of sulfur content) grades of coal, which constitutes our second testable hypothesis. Our third hypothesis is that, in response to this fall in price, coal use by utilities would increase. Our final hypothesis is that, given the expected increase in the sulfur premium for coal, utilities would find it advantageous to temporarily shift to higher-sulfur coal. Thus, we should be able to observe an increase in the sulfur content of coal delivered after the signing into law of the ARP.

We use data on coal deliveries to U.S. coal-fired power plants to test these hypotheses. We find strong evidence in support of the first two hypotheses. The average monthly price of coal delivered on the spot market dropped by 9% after the announcement of the ARP, and the sulfur premium increased by roughly 40%. We are also able to identify the quantity effect postulated in our third hypothesis, albeit only in a subset of plants. In particular, we find that only power plants that were

[20] The results in Table 5 indicate a reduction in intensity equal to between 0.15 and 0.26 lbs/MBtu (4.7–8%), which corresponds to a decrease in SO_2 emissions of 9800–17 000 tons.

sufficiently flexible in their procurement strategies seem to have increased their heat input (by 13–16%) in response to the lower price of coal. It stands to reason that plants that rely heavily on long-term contracts for their coal supply would have neither the possibility nor the inclination to purchase cheaper coal via spot-market operations. Finally, we do not find evidence in support of the final hypothesis, that the sulfur content of coal would increase. Our results show that coal deliveries from spot market contracts rather exhibited a shift towards cleaner coal as early as 1991. These results, however, are driven by the behaviour of firms operating in states that required the pre-submission of compliance plans for the ARP. Such firms are shown to have reduced the sulfur intensity of their coal already in the interim phase, possibly in the pursuit of early compliance assurance.

In conclusion, going back to the question asked in our title, should we be worried about the green paradox? Based on the evidence discussed above, it seems that an appropriate answer might be "yes … well, maybe … probably not!". Indeed, despite a significant drop in coal prices, few power plants actually responded to the price signal by increasing their coal use, while sulfur content does not appear to have increased. Overall, aggregate emissions have not been significantly higher due to the policy announcement than they would otherwise have been. While our results regarding the existence of a green paradox are somewhat mixed, however, they do suggest that fossil fuel prices react to policy announcements as predicted by the theory. The reasons why power plants did not react more strongly to the price signal are to be found in the reality of the coal-based generation industry in the United States.

First of all, one must consider that the actual power-plants we analyze are different from the stylized agents portrayed in the theoretical literature. Coal-fired powered plants in the U.S. in the early 1990s operated under economic regulation, and their incentives to switch fuel in pursue of economic profits might have been muted relative to their theoretical counterparts operating in frictionless electricity markets. Secondly, most of the plants in our sample are large base-load plants, producing at full capacity almost all the time. Their technical ability to produce more might have been severely constrained in the short run. Given the length of the implementation lag, power plants might simply not have had enough time to make the capacity adjustments necessary to benefit from the fall in coal prices. Besides the technical and administrative difficulties in getting new capacity on-line, it might have made little economic sense to adjust the productive capacity of a power plant in order to exploit a business advantage spanning only a few years. It is also important to remember that in this industry coal procurement was largely based on long-term contracts, and that the spot market had a limited scale. Both these factors limit the possibility to adjust coal quantities in response to changes in prices, as we have shown in Table 3. A final important aspect is that the industry is subject to a plethora of competing regulations, with local, state and federal rules overlapping and interacting with each other in a highly complex way (see Rose, 1997). For example, Lile and Burtraw (1998) provide an interesting compendium on how state rules might have biased compliance options for Phase I plants towards capital intensive ones, and promoted self-compliance over trading. They also discuss the role of pre-approval of compliance plants, which would favour early compliance over green-paradoxical increases in emissions. This last suggestion is consistent with our results in Table 5. Overall, we find that economic, technical and administrative constraints in this industry made the demand for coal very irresponsive to changes in prices over short time periods, thus limiting the likelihood that a green paradox would emerge (Di Maria et al., 2013).

Our results support the view that the green paradox is more than a scientific curiosum and that there might be reasons to be worried. Despite a number of unilateral policy initiatives by a limited number of countries, the largest emitters on the planet do not appear likely to face stringent climate policies for many years to come. Moreover, while the low elasticity of demand for coal appears to have reduced the tendency to increase emissions in our case study, the demand for energy is continuously increasing in most developing countries, and fossil fuels are likely to be highly demanded for the foreseeable future. In these circumstances, fossil fuel users would be ideally positioned to exploit any reduction in prices, making the emergence of a green paradox much more likely.

Our discussion above, however, suggests that there is a role that policy can play to limit the emergence of a green paradox. Indeed, policy design might reduce the possibility of a green paradox by reducing the elasticity of demand for fossil fuels. The policy prescriptions that emerge from our analysis are simple. Firstly, policymakers should limit the length of any implementation lag to reduce the time horizon over which polluters might increase their use of fossil fuels. Secondly, they could resort to administrative controls (building permissions/permissions to operate) to limit the possibility that new polluting capacity be added to the pool of power plants, locking in undesirable technologies. Finally, as shown above, U.S. power plants located in states with strict pre-existing policies, and especially with policies that required pre-approval of compliance plans, were less able to exploit lower coal prices. Thus, demand reducing policies that specify appropriate milestones or ask regulated firms to submit compliance plans in advance of the policy's implementation, seem to hold much promise in terms of avoiding a green paradox.

Appendix A. Data

Descriptive statistics of all variables are provided in Table A.1.

We use information for the period 1987–1999 for our analysis. This time period starts three years before the 1990 CAAA was passed and ends at the start of Phase II of the ARP. The sample of plants in our main source of data, the U.S. Federal Energy Regulatory Commission (FERC) form FERC-423 'Monthly Cost and Quality of Fuels for Electric Plants', shrinks after 1999 as plants in restructured electricity markets are dropped from the sample by the FERC. The sample begins in 1987 to

Table A.1
Descriptive statistics.

Sample Variable	(1) Full sample Mean (S.D.)	(2) Before 1990 CAAA Mean (S.D.)	(3) After 1990 CAAA Mean (S.D.)	(4) Phase I Mean (S.D.)	(5) Non Phase I plants in States with Phase I Plants Mean (S.D.)	(6) NSPS-Da Plants in States with Phase I Plants Mean (S.D.)	(7) Diff. (5)–(4)
Spot price (Real U.S.¢/MBtu)	171.64	178	164.42	160.58	177.87	181.23	17.04***
	(42.85)	(43.38)	(39.97)	(33.11)	(42.49)	(39.07)	(0.65)
Spot SO_2 intensity (lbs/MBtu)	2.33	2.43	2.21	3.16	2.24	2.29	−0.91***
	(1.47)	(1.46)	(1.47)	(1.42)	(1.45)	(1.33)	(0.02)
Total heat (GBtu)	3429.94	3359.74	3517.78	4388.5	2747.35	3909.25	−1641.15 ***
	(3462.57)	(3407.09)	(3528.15	(3649.9	(3177.12)	(2364.87)	(42.13)
State output (Coincident Index)	96.78	91.68	103.11	96.77	97.37	97.88	0.58***
	(8.65)	(7.29)	(5.42)	(8.68)	(8.45)	(7.91)	(0.1)
Gas price (U.S.¢/,000 cu ft)	318.04	297.68	341.53	317.99	318.06	322.59	0.17
	(54.99)	(64.04)	(27.39)	(55.2)	(54.92)	(51.35)	(0.7)
Productivity (ton/employee hour)	5.03	4.39	5.83	3.25	4.42	4.80	1.18***
	(3.53)	(3.01)	(3.95)	(1.75)	(3.15)	(3.58)	(0.02)
Rail price (Real U.S.¢/ton mile)	3.09	3.58	2.49	3.10	3.09	3.00	0.01
	(0.73)	(0.66)	(0.14)	(0.73)	(0.73)	(0.69)	(0.01)
Plant w/ Scrubber	0.20	0.19	0.21	0.05	0.20	0.75	0.15***
	(0.40)	(0.39)	(0.40)	(0.22)	(0.43)	(0.69)	(0.01)
Mandatory Phase I plants	0.22						
	(0.41)						
Appalachian heat share	0.45	0.46	0.45	0.51	0.53	0.41	0.02***
	(0.48)	(0.48)	(0.48)	(0.47)	(0.48)	(0.46)	(0.01)
Interior heat share	0.23	0.24	0.21	0.42	0.23	0.27	−0.19***
	(0.41)	(0.41)	(0.38)	(0.46)	(0.40)	(0.43)	(0.01)
Western heat share	0.30	0.28	0.32	0.06	0.21	0.27	0.15**
	(0.44)	(0.44)	(0.45)	(0.20)	(0.39)	(0.44)	(0.01)
Import heat share	0.01	0.01	0.01	0.01	0.01	0.04	0.04***
	(0.04)	(0.03)	(0.06)	(0.01)	(0.05)	(0.13)	(0.01)
No nuclear state	0.23			0.31			
	(0.42)			(0.45)			
High spot procurement	0.25			0.27			
	(0.23)			(0.18)			
Pre-approval	0.17			0.37			
	(0.38)			(0.48)			
Strict env. regulations	0.15			0.08			
	(0.35)			(0.27)			
Number of plants	418	409	418	89	329	201	

*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.

avoid including the changing structure of the coal market in the pre-policy period. As discussed in Ellerman and Montero (1998) and Kozhevnikova and Lange (2009), a larger share of coal was coming from the Western coal basin and transacted in the spot market by 1987 relative to earlier in the decade.

FERC-423 contains a panel dataset with monthly information on the cost and quality of coal deliveries to plants of 50 MW or larger capacity. The dataset records both deliveries made as part of long-term contracts, and deliveries that originate from spot purchases on the market. We obtain data on coal prices, sulfur content, heat content, ash content, region of origin of coal delivered and the share of coal from spot deliveries from this dataset.

Data on the NSPS status of plants were generously provided by Danny Ellerman.

Our proxy for monthly transport costs in cents per million Btu is constructed using the average distance of each plant to each of the three mining regions (from the EIA's Coal Transportation Rate Database), the rail rates variable 'Rail Price' (see below), the size of the delivery in tons, and total heat delivered to the plant from each of the three regions.

Data on state-level output, to control for business cycle effects and industrial activity at the state level, are obtained from the Coincident Economic Activity Index of the Federal Reserve Bank of St. Louis. The monthly index includes nonfarm payroll employment, the unemployment rate, average hours worked in manufacturing and wages and salaries.[21]

[21] State-level GDP data are only available from 1997 onwards.

Data on the gas price are taken from U.S. EIA (2010), are in U.S. dollar cents per thousand cubic feet and are discounted using the PPI for crude energy to 1982 dollars. Data on electricity generation from natural gas are collected from the Annual Energy Review, which is published by the U.S. Energy Information Administration (U.S. EIA, 2005).

'Scrubber' is a dummy variable equal to one in each month in which a plant had a flue gas desulfurization unit (SO_2 control equipment, also known as a 'scrubber') installed. It is constructed using data from EIA Form 767.

The summer dummy equals one during the months June, July, August and September and is zero otherwise. The winter dummy equals one during the months December, January, February and March and is zero otherwise.

The rail rates variable 'Rail Price' is created with data from the EIA (U.S. EIA, 2004) on the average rate per ton-mile per year, deflated with the producer price index. The variable 'Close to PRB' includes Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Nebraska, Oklahoma, Texas, Washington and Wisconsin.

Coal mines are assigned to coal mining regions following Joskow (1987). Regional coal mine productivity data are obtained from U.S. EIA (2010).

Information on whether the state the Phase I plant is located has strict environmental standards and whether the state the Phase I plant is located in required a compliance plan prior to the start of the ARP come from Lile and Burtraw (1998).

Data on whether state has a nuclear plant located in it are obtained from U.S. EIA (2011c), whereas the capacity utilization data is derived from U.S. EIA (2006).

Appendix B. Additional Tables (Tables B.1–B.5.)

Table B.1
Hedonic coal price regressions—coefficients omitted from Table 1.

Dependent variable	Weighted average real price[a]	
Sample	(1) Spot transactions	(2) Spot transactions for plants in states with Phase I plants Coefficient (S.E)
Productivity	−4.55***	−3.35***
	(0.86)	(1.16)
Heat content	0.00	0.00
	(0.00)	(0.00)
Ash content	0.46**	0.49**
	(0.18)	(0.22)
Share West	−8.74	−19.82*
	(9.16)	(10.39)
Share Interior	−7.16*	−8.67**
	(3.80)	(3.30)
Share Import	−19.21***	−11.25
	(6.01)	(7.76)
Transport costs	−0.03	0.01
	(0.04)	(0.04)
Gas price	0.05***	0.05***
	(0.01)	(0.01)
Constant	214.83***	208.35***
	(4.76)	(5.46)
Observations	19863	15799
Plants	367	276
R^2	0.27	0.21
F	130.19	145.47

Regressions include plant dummies.
Standard errors corrected for panel serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

[a] Average delivery price, weighted by heat-content for each plant, month.

Table B.2
Heat input hypothesis—coefficients omitted from Table 2.

Dependent variable	Natural log of total heat purchased			
Sample	All transactions (1) Coefficient (S.E.)	All transactions for plants in states with Phase I plants (2) Coefficient (S.E.)	All transactions for Phase I plants or NSPS-Da plants in states with Phase I plants (3) Coefficient (S.E.)	All transactions for Phase I plants or high utilization NSPS-Da plants in states with Phase I plants (4) Coefficient (S.E)
State GDP	0.01***	0.01*	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Scrubber	0.37	0.29	0.12	−0.12
	(0.27)	(0.37)	(0.35)	(0.32)
Gas price	0.00	0.00**	0.00***	0.00**
	(0.00)	(0.00)	(0.00)	(0.00)
Summer	0.04***	0.03**	0.03*	0.01*
	(0.01)	(0.01)	(0.01)	(0.01)
Winter	−0.02	−0.03	−0.04	−0.04
	(0.02)	(0.03)	(0.03)	(0.03)
1987	0.03	0.02	0.02	0.01
	(0.02)	(0.04)	(0.05)	(0.04)
1988	−0.02	−0.06	−0.08	−0.09
	(0.04)	(0.05)	(0.06)	(0.06)
1989	−0.02	−0.11	−0.12	−0.12
	(0.06)	(0.08)	(0.09)	(0.09)
1990	−0.02	−0.09	−0.11	−0.09
	(0.06)	(0.07)	(0.09)	(0.09)
1991	−0.04	−0.12*	−0.16**	−0.14*
	(0.05)	(0.07)	(0.07)	(0.08)
1992	−0.07	−0.18**	−0.20**	−0.17*
	(0.07)	(0.08)	(0.09)	(0.09)
1993	−0.07	−0.17**	−0.18**	−0.20**
	(0.06)	(0.07)	(0.08)	(0.08)
1994	−0.04	−0.11	−0.12	−0.16*
	(−0.04)	(0.08)	(0.08)	(0.09)
Constant	6.79***	6.83***	6.89***	7.04***
	(0.19)	(0.27)	(0.28)	(0.25)
Observations	38315	27190	22314	19395
Plants	401	288	237	223
R^2	0.02	0.01	0.01	0.002
F	31.43	1283.69	3731.68	1407.30

Controls for all regressions are State GDP, Scrubber Dummy, Real Natural Gas Price, Summer, Winter, Year and Plant Dummies.
Standard errors corrected for panel serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1987–1994.

Table B.3
Heat input hypothesis, additional results—coefficients omitted from Table 3.

Dependent variable	Natural log of total heat purchased					
Sample	(1) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(2) All transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(3) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(4) All transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(5) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(6) All transactions for plants in states with Phase I plants Coefficient (S.E.)
State GDP	0.01*	0.00	0.01*	0.00	0.01*	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Scrubber	0.27	0.10	0.27	0.10	0.28	0.10
	(0.38)	(0.36)	(0.38)	(0.36)	(0.38)	(0.36)
Gas price	0.00*	0.00***	0.00*	0.00***	0.00*	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Summer	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
Winter	−0.04	−0.04	−0.04	−0.04	−0.04	−0.04
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)

Table B.3 (*continued*)

Dependent variable	Natural log of total heat purchased					
Sample	(1) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(2) All transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(3) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(4) All transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(5) All transactions for plants in states with Phase I plants Coefficient (S.E.)	(6) All transactions for plants in states with Phase I plants Coefficient (S.E.)
1987	0.02	0.01	0.02	0.01	0.02	0.01
	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)
1988	−0.07	−0.09*	−0.08	−0.09*	−0.07	−0.09*
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
1989	−0.11*	−0.13*	−0.12*	−0.13*	−0.12*	−0.13*
	(0.06)	(0.07)	(0.06)	(0.07)	(0.06)	(0.07)
1990	−0.07	−0.09	−0.08	−0.09	−0.07	−0.09
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
1991	−0.08	−0.11	−0.09	−0.11	−0.09	−0.11
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
1992	−0.13	−0.14	−0.13*	−0.14*	−0.13	−0.13
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
1993	−0.15*	−0.16*	−0.16*	−0.16*	−0.16*	−0.15*
	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)
1994	−0.09	−0.10	−0.10	−0.11	−0.10	−0.10
	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)
Constant	6.88***	6.91***	6.84***	6.91***	6.86***	6.92***
	(0.26)	(0.30)	(0.25)	(0.28)	(0.25)	(0.27)
Observations	27 190	22 314	27 190	22 314	27 190	22 314
Plants	288	237	288	237	288	237
R^2	0.01	0.001	0.01	0.005	0.01	0.004
F	480.93	51.93	111.85	66.39	92.21	45.26

Regressions include Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time Period is 1986–1994.

Table B.4
Intensity hypothesis—coefficients omitted from Table 4.

Dependent variable	Sulfur intensity (SO_2 lbs/MBtu)			
Sample	(1) Spot transactions Coefficient (S.E.)	(2) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(3) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(4) All transactions Coefficient (S.E.)
Scrubber	0.35	0.54	0.55	0.12
	(0.38)	(0.37)	(0.41)	(0.16)
Share West	−0.88***	−1.00***	−1.11***	−0.64**
	(0.17)	(0.17)	(0.15)	(0.25)
Share Interior	1.66***	1.75***	1.78***	2.05***
	(0.16)	(0.15)	(0.15)	(0.31)
Share Import	−0.86***	−0.83***	−0.83***	−0.86***
	(0.21)	(0.26)	(0.26)	(0.23)
Rail costs	−0.00	0.00	−0.01	0.06*
× PRB range	(0.04)	(0.04)	(0.05)	(0.03)
1987	0.04	0.06	0.05	0.03**
	(0.03)	(0.04)	(0.05)	(0.01)
1988	0.05	0.06	0.05	0.03**
	(0.05)	(0.07)	(0.08)	(0.02)
1989	0.04	0.08	0.04	0.03
	(0.04)	(0.05)	(0.06)	(0.02)
1990	0.08	0.11	0.13**	0.05*
	(0.05)	(0.07)	(0.06)	(0.03)
1991	0.07*	0.08	0.09*	0.03
	(0.04)	(0.05)	(0.05)	(0.03)
1992	0.05	0.07	0.04	0.01
	(0.06)	(0.07)	(0.09)	(0.03)
1993	0.04	0.05	−0.02	−0.00
	(0.06)	0.08	(0.09)	(0.03)

Table B.4 (*continued*)

Dependent variable	Sulfur intensity (SO_2 lbs/MBtu)			
Sample	(1) Spot transactions Coefficient (S.E.)	(2) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(3) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)	(4) All transactions Coefficient (S.E.)
1994	0.12**	0.12*	0.05	0.02
	(0.05)	(0.07)	(0.08)	(0.03)
Constant	2.07***	2.19***	2.30***	1.87***
	(0.08)	(0.09)	(0.09)	(0.17)
Observations	20 563	16 396	13 804	40 766
Plants	369	277	228	409
R^2	0.42	0.40	0.35	0.47
F	102.22	2204.40	38408.65	223.76

Regressions include Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

Table B.5
Intensity hypothesis: additional results—coefficients omitted from Table 5.

Dependent variable Sample	Sulfur intensity (SO_2 lbs/MBtu)			
	(1) Spot transactions for plants in states with Phase I plants Coefficient (S.E.)	(2) Spot transactions for phase I or NSPS-Da plants for states with phase I plants Coefficient (S.E.)	(3) Spot transactions for plants in states with phase I plants Coefficient (S.E.)	(4) Spot transactions for Phase I or NSPS-Da plants for states with Phase I plants Coefficient (S.E.)
Scrubber	0.54	0.57	0.54	0.56
	(0.38)	(0.43)	(0.36)	(0.41)
Share West	−1.01***	−1.12***	−1.00***	−1.12***
	(0.16)	(0.16)	(0.17)	(0.15)
Share Interior	1.74***	1.76***	1.75***	1.76***
	(0.15)	(0.15)	(0.15)	(0.15)
Share Import	−0.82***	−0.84***	−0.84***	−0.84***
	(0.26)	(0.27)	(0.26)	(0.26)
Rail costs	0.00	−0.01	0.00	−0.01
× PRB range	(0.04)	(0.05)	(0.05)	(0.05)
1987	0.03	0.02	0.03	0.02
	(0.03)	(0.04)	(0.04)	(0.04)
1988	0.05	0.03	0.04	0.03
	(0.06)	(0.07)	(0.06)	(0.07)
1989	0.09**	0.07	0.09*	0.07
	(0.04)	(0.05)	(0.05)	(0.05)
1990	0.09	0.10	0.09	0.10
	(0.06)	(0.06)	(0.06)	(0.06)
1991	0.01	0.02	0.01	0.02
	(0.06)	(0.07)	(0.07)	(0.07)
1992	−0.01	−0.03	−0.02	−0.03
	(0.07)	(0.09)	(0.08)	(0.08)
1993	−0.03	−0.07	−0.03	−0.06
	(0.07)	(0.08)	(0.07)	(0.08)
1994	0.03	−0.02	0.03	−0.01
	(0.07)	(0.09)	(0.08)	(0.09)
Constant	2.18***	2.31***	2.19***	2.30***
	(0.09)	(0.08)	(0.09)	(0.09)
Observations	16396	13804	16396	13804
Plants	277	228	277	228
R^2	0.40	0.36	0.40	0.36
F	669.86	3232.05	186.88	369.97

Regressions include Plant Dummies.
Standard errors corrected for state-level serial correlation.
*, **, *** indicate 10%, 5% and 1% statistical significance, respectively.
Time period is 1986–1994.

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