Manufacturing & Service Operations Management

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Operational Compliance Levers, Environmental Performance, and Firm Performance Under Cap and Trade Regulation

James Kroes, Ravi Subramanian, Ramanath Subramanyam,

MANUFACTURING & SERVICE OPERATIONS MANAGEMENT
Vol. 14, No. 2, Spring 2012, pp. 186–201
ISSN 1523-4614 (print) | ISSN 1526-5498 (online)
http://dx.doi.org/10.1287/msom.1110.0357

Operational Compliance Levers, Environmental Performance, and Firm Performance Under Cap and Trade Regulation

James Kroes
College of Business and Economics, Boise State University, Boise, Idaho 83725, jimkroes@boisestate.edu

Ravi Subramanian
College of Management, Georgia Institute of Technology, Atlanta, Georgia 30332, ravi.subramanian@mgt.gatech.edu

Ramanath Subramanyam
Department of Business Administration, University of Illinois at Urbana–Champaign, Champaign, Illinois 61820, rsubrama@illinois.edu

Cap and trade programs impose limits on industry emissions but offer individual firms the flexibility to choose among different operational levers toward compliance, including inputs, process changes, and the use of allowances to account for emissions. In this paper, we examine the relationships among (1) levers for compliance (at-source pollution prevention, end-of-pipe pollution control, and the use of allowances); (2) environmental performance; and (3) firm market performance for the context of stringent cap and trade regulation with allowance grandfathering (i.e., the allocation of allowances for free). To investigate these relationships, we use data on publicly traded utility firms operating coal-fired generating units regulated by the U.S. Acid Rain Program from three principal sources: the U.S. Energy Information Administration, the U.S. Environmental Protection Agency, and the Compustat database. Our results indicate a significant relationship between better environmental performance and lower firm market performance over at least a three-year period. From a regulatory perspective, our results show a negative association between allowance grandfathering and firm environmental performance. Overall, by explicitly considering the context of stringent regulation, we find a counter-example to the view that better environmental performance generally associates with better economic performance.

Key words: environmental operations; public policy; environmental compliance; cap and trade; empirical research
History: Received: January 29, 2010; accepted: September 2, 2011. Published online in *Articles in Advance* February 2, 2012.

1. Introduction

Market-based cap and trade programs for controlling pollutants such as sulfur dioxide (SO_2) and carbon dioxide (CO_2) have come to the forefront of environmental policy making, displacing traditional command-and-control programs (Ellerman 1998, McKinnon 2007, Napolitano et al. 2007, Ball 2008). A primary reason for this regulatory shift is the recognition that historical command-and-control methods fall short of offering firms the flexibility to choose among different operational levers for compliance and do not ensure that intended emissions goals will be met (Majumdar and Marcus 2001). Many national and international agencies have proposed cap and trade as a mechanism to control pollutant emissions; however, the environmental and economic effects of such regulation are a matter of significant debate (Yale Environment 360, 2009). Additionally, the bulk of the discussion on cap and trade regulation focuses on its effectiveness to reduce pollution and the burden on taxpayers, whereas a smaller portion of the debate concerns the economic impact on the affected firms—particularly the relationship between a firm's environmental performance arising from compliance choices and its economic performance. However, the impact of such regulation on affected firms is perhaps most interesting from an operations management perspective. Managers must understand not only the environmental effectiveness of compliance choices but also the associated effects on the firm's economic performance in order to be able to make strategic compliance decisions.

In cap and trade programs (also referred to as emissions trading), the regulator issues *allowances* or *permits* corresponding in number to the intended aggregate cap on emissions. Emitting sources are required to have a valid allowance for each unit of pollutant emitted (Ellerman et al. 1997). The rationale behind such programs is that firms should be allowed the flexibility to choose from a variety of compliance levers as long as emissions are accounted for with the requisite number of allowances (Ingebretsen and Sweet 2003, Taylor 2009). Further, if a firm reduces emissions below its allocated level, the unused allowances can either be banked for future use or sold in the allowance market. Likewise, a firm could emit *above* its allocated level by purchasing additional allowances. This flexibility theoretically allows firms to comply with emissions caps in a cost-effective manner (Stavins 1998, Burtraw and Mansur 1999, Taylor et al. 2005).

The U.S. Acid Rain Program is the only fully implemented national or international cap and trade program that has successfully reduced emissions of the targeted pollutant (U.S. Environmental Protection Agency (EPA) 2010b). The program, established under Title IV of the 1990 Clean Air Act Amendments, mandates reductions of SO_2 emissions from utility owned, fossil fuel–fired electricity generating units in two phases. In Phase 1 (1995–1999), generating units of 100 MW_e (megawatt electrical) capacity or greater and having an SO_2 emissions rate in 1985 of 2.5 pounds per million Btu (lbs/mmBtu) of heat input or higher were required to reduce annual SO_2 emissions to 2.5 lbs/mmBtu multiplied by the average annual heat input during 1985–1987. Phase 2, which began in the year 2000, includes generating units greater than 25 MW_e capacity (accounting for about 99% of all coal-fired electricity generation capacity in the United States) and requires affected units to reduce annual SO_2 emissions to about 1.2 lbs/mmBtu multiplied by the average annual heat input during 1985–1987 (Joskow et al. 1998, Ellerman 2003b). Allowances corresponding in number to the reduced SO_2 emissions rate are *grandfathered* (i.e., allocated free of charge to the affected units) based on the "nonobservable" prior-period baseline. A small fraction of these allowances are set aside for annual auctions via the Special Allowance Reserve (EPA 2010a). Nonobservability of the baseline is important to preclude "baseline gaming." Further, the grandfathering of SO_2 allowances was on the basis of historical *heat input* as opposed to *emissions output* so as to not unfairly benefit the firms that polluted more prior to regulation (Ellerman et al. 2003). The year 2010 SO_2 cap of 8.95 million tons is about 50% of the year 1980 SO_2 emissions from the power sector (EPA 2002). By the end of 2006, affected sources had reduced annual SO_2 emissions by 40% compared to 1990 levels (EPA 2007).

The principal compliance levers available to firms operating under cap and trade programs include at-source methods (such as switching to a less polluting input), end-of-pipe methods (such as installing equipment for removing or neutralizing pollutants), and obtaining allowances to account for emissions (EPA 2007). These come at a significant cost and can potentially affect the economic performance of the affected firms. In particular, the challenge posed by the U.S. Acid Rain Program to the electric utility industry has been substantial because of the rather stringent cap on emissions (Marcus and Geffen 1998). For example, PSI Energy reported the costs of employing the aforementioned methods to comply with the provisions of the program as follows (*Business Wire* 2005):

> This is our company's largest environmental construction program.... We will invest more than $1 billion to burn coal more cleanly and improve air quality.... Phase 1 of PSI's environmental plan totals $1.07 billion and primarily includes:
>
> —Flue gas desulfurization equipment, or "scrubbers," [*end-of-pipe method*] at larger coal-fired generating units that are not already scrubbed, including three units at Gibson Station [3,340 MW_e total nameplate capacity] near Princeton and two units at Cayuga Station [1,062 MW_e total nameplate capacity] north of Terre Haute.... Scrubber installations will allow the use of a greater variety of coal and lessen the companies' dependence on volatile sulfur dioxide emission allowance markets [*using allowances*]....
>
> —Bag house technology at Gallagher Station [600 MW_e total nameplate capacity]. The bag houses will allow Gallagher to use lower-sulfur coal [*at-source method*], which will reduce the station's sulfur dioxide emission rate....

In an attempt to gain insights into the firm-level environmental and economic effects of cap and trade regulation, this study examines the relationship between operational compliance levers (at-source, end-of-pipe, and allowances); environmental performance; and firm market performance when firms are regulated by a cap and trade program for reducing emissions. To conduct our empirical analyses, we gather data on publicly traded utility firms operating coal-fired generating units affected by the U.S. Acid Rain Program from three principal sources—the U.S. Energy Information Administration (EIA), the U.S. Environmental Protection Agency (EPA), and the Compustat database.

Notably, the Massachusetts Institute of Technology Center for Energy and Environmental Policy Research (CEEPR) has published a series of empirical studies on the implementation of the U.S. Acid Rain Program and compliance behavior by the affected utility firms (CEEPR 2010). However, the main point of departure in our work is that we aim to understand *whether there exist market benefits for firms that operate more cleanly under a stringent yet flexible regulatory program*. A related concern that has not been investigated in prior research is whether common policy provisions such as allowance grandfathering, which are intended to help polluting firms transition to a cleaner state, associate with negative environmental outcomes. Thus, we hope to contribute to the existing debate on cap and trade programs through our empirical analyses.

This paper is organized as follows. Section 2 develops our conceptual framework and introduces our hypotheses. Section 3 describes the data collection process and introduces our measures. Section 4 presents our empirical analysis and summarizes our results. Section 5 includes a discussion of our results. Because our findings are based on an analysis of a specific cap and trade program affecting a specific industry, we also discuss the caveats to our findings in §5. Section 6 concludes the paper.

2. Theory and Hypotheses

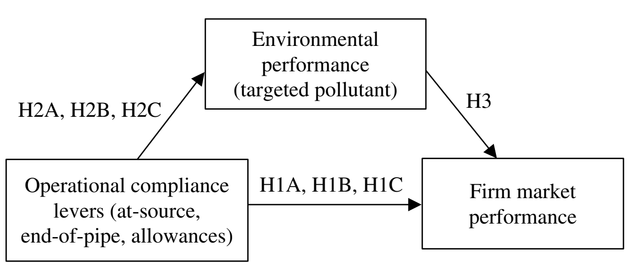
Operations decisions pertaining to inputs, processes, and products directly impact not only the economic viability of any business but also the types and amounts of pollutants released into the different discharge media (air, water, and land). Sound operations management is thus inextricably linked with both economic and environmental performance (Klassen and McLaughlin 1996, Angell and Klassen 1999, Corbett and Klassen 2006). Regulatory pressures make it all the more imperative for businesses to understand these linkages to ensure that both economic and environmental objectives are met (Corbett and Kleindorfer 2001, Linton et al. 2007).

Our conceptual framework (Figure 1) integrates the relationships among operational compliance levers, environmental performance, and firm market performance. Prior literature has examined various subsets of the relationships depicted in Figure 1. In §§2.1–2.3, we synthesize the discussions and findings in the literature within our framework and present our hypotheses for the context of stringent cap and trade regulation.

2.1. Operational Compliance Levers and Firm Performance

As described in §1, cap and trade programs give firms the flexibility to choose among different compliance levers. With regard to other typology used

Figure 1 **Conceptual Framework**



in the literature, at-source levers would correspond to "pollution prevention," whereas end-of-pipe levers would correspond to "pollution control" (Klassen and Whybark 1999).

Prior literature has examined the linkage between a firm's environmental efforts and economic or operational performance. King and Lenox (2002) examine the relationship between pollution reduction efforts and financial performance for U.S. firms participating in the EPA's Toxics Release Inventory program. They find that pollution prevention trumps pollution control in positively impacting firm market performance. The general position in the literature is that pollution prevention has analogies with total quality management in that it avoids waste and entails employee involvement and continuous improvement as opposed to "nonproductive" pollution control. At-source pollution prevention may also avoid the costs of having to install end-of-pipe pollution control equipment. Other benefits of pollution prevention that have been identified in the literature include lower waste disposal costs and the reduction of potential liabilities (Rooney 1993, Hart 1995). In a related study, Klassen and Whybark (1999) provide empirical evidence that manufacturing performance (including cost and speed) is superior when investments in the "environmental technology portfolio" (i.e., the pattern of investments in environmental technologies over time) are weighted more toward pollution prevention.

To complement this literature, we investigate the relationship between operational compliance levers and firm market performance by explicitly taking into account the regulatory environment in which the firms operate. Further, by specifically examining firms regulated under a stringent cap and trade program, our study takes into account unique factors associated with such regulation. In particular, we provide below an account of the costs incurred by coal-fired electric utilities in implementing the principal compliance levers, namely, at-source fuel switching, end-of-pipe scrubbing, and the use of allowances (Ellerman 2003b) in response to the provisions of the U.S. Acid Rain Program.

2.1.1. Subbituminous Coal Usage (At-Source Pollution Prevention). Coal is classified under four general types, or "ranks"—lignite, subbituminous, bituminous, and anthracite—depending upon carbon content and the amount of recoverable heat energy. Subbituminous and bituminous coals account for the vast majority of electricity generation in the United States, with subbituminous coals having lower (as low as one-ninth) sulfur content as compared to bituminous coals (Riley 2007). Switching to subbituminous coal implies additional handling and processing costs because of its lower heat content and higher moisture content (Marcus and Geffen 1998, FERC 2004). Although the coal prices paid by utility firms are private information (FERC 2004), Carlson et al. (2000) estimate the total cost of fuel switching to be $291 per ton of SO_2 removed (in year 2000 dollars). To give a sense of the overall scale of costs, over the period covered by our study (2004–2006), affected publicly traded utility firms that used coal as the primary energy source (i.e., where coal accounted for more than 50% of the firm's total electricity generated over 2004–2006) emitted an average of about 167,000 tons of SO_2 annually. Hence, although fuel switching is analogous to pollution prevention in that it avoids the costs of installing and operating expensive pollution control equipment, switching to subbituminous coal itself involves significant costs and has the potential to negatively affect firm market performance. Thus, we hypothesize the following:

Hypothesis 1A (H1A). *Greater use of an at-source lever associates with lower firm market performance.*

2.1.2. Flue Gas Desulfurization (FGD, End-of-Pipe Pollution Control). FGD is the process of chemically removing SO_2 from exhaust flue gases (EPA 2003). FGD units vary in their sulfur removal efficiencies and require significant capital outlays. For example, in the year 1995, American Electric Power (AEP) spent $662 million to install an FGD unit at a $1.7 billion site (AEP 2003; amounts are in year 1999 dollars). In addition, there are significant costs involved in operating and maintaining FGD units. As is the case with prices paid for coal, the costs of installing and operating FGD units are not public information (EIA 2010). However, Carlson et al. (2000) estimate the total cost of reducing SO_2 emissions through FGD to be $360 per ton of SO_2 removed (in year 2000 dollars). Thus, consistent with the expectation for end-of-pipe pollution control in the prior literature, the costs associated with the use of FGD have the potential to negatively affect firm market performance. Accordingly, we hypothesize the following:

Hypothesis 1B (H1B). *Greater use of an end-of-pipe lever associates with lower firm market performance.*

2.1.3. Grandfathered Allowances. Firms regulated by the Acid Rain Program must surrender an allowance for each ton of SO_2 emitted. Under the provisions of the program, annual allowances are grandfathered to affected firms based on the average heat input of the fossil fuel–fired units operated by the firms during the period 1985–1987 (Ellerman 2003a). These allowances, plus allowances banked from previous years, correspond to the annual emissions cap for the industry. Although firms that emit SO_2 below their grandfathered levels can either sell their unused allowances or bank them for future use, the grandfathering of allowances cushions firms from having to make costly investments in fuel switching or scrubbing (EPA 1998, Smith et al. 1998, Carlson et al. 2000). From 2004 to 2006, affected publicly traded utility firms that used coal as the primary energy source were grandfathered about 77% of the needed allowances. The ability of grandfathered allowances to enable cost-effective regulatory compliance in lieu of investments in pollution reduction leads us to hypothesize the following:

Hypothesis 1C (H1C). *A greater level of allowance grandfathering associates with better firm market performance.*

2.2. Operational Compliance Levers and Environmental Performance

The literature provides arguments that motivate the positive relationship between pollution prevention efforts and environmental performance (i.e., lower emissions). Hart (1995) posits that because pollution prevention accumulates tacit resources among employees, related efforts should be associated with simultaneous improvements in both environmental and firm performance. Klassen and Whybark (1999) provide evidence using survey and secondary data that environmental performance, measured as the release or transfer of toxic chemicals, improves when investments in the environmental technology portfolio are weighted more toward pollution prevention. They also posit that because it only either secures or converts the pollutant, pollution control does not significantly change the ultimate quantities of pollutants released across the different discharge media.

The literature also discusses how initial emissions reduction efforts result in disproportionate improvements in environmental performance and that additional improvements require significant process or technology changes (Hart and Ahuja 1996). In other words, at-source pollution prevention is likely to be associated with diminishing returns to environmental performance, and end-of-pipe pollution control may have to be pursued additionally if emissions caps are stringent.

With a stringent cap on a specific pollutant within a targeted medium (air, water, or land), an affected firm's operational focus would likely narrow down to the targeted pollutant and medium as opposed to reductions of overall releases. In such a scenario, end-of-pipe methods may be attractive for mitigating the amount of pollutant discharged into the targeted medium beyond the reductions offered by at-source pollution prevention. Thus, under a stringent cap on emissions into a targeted discharge medium, we expect that firms would have to employ both at-source and end-of-pipe levers in combination to meet the cap. Thus, for our context, we predict the following:

Hypothesis 2A (H2A). *Greater use of an at-source lever associates with better environmental performance in terms of the targeted pollutant.*

Hypothesis 2B (H2B). *Greater use of an end-of-pipe lever associates with better environmental performance in terms of the targeted pollutant.*

On the other hand, we posit that the policy measure of grandfathering free allowances to offset emissions diminishes the incentive for firms to operate cleanly, despite the tradability of allowances. Hence, we hypothesize the following:

Hypothesis 2C (H2C). *A greater level of allowance grandfathering associates with lower environmental performance in terms of the targeted pollutant.*

2.3. Environmental Performance and Firm Performance

Prior literature provides contrasting viewpoints of the relationship between environmental performance per se and firm performance. Broadly speaking, one view is that better environmental performance reduces compliance costs; implies superior efficiency, productivity, and organizational capabilities; and associates with favorable public image, stakeholder relations, and market perception (Porter and van der Linde 1995, Russo and Fouts 1997). Empirical support of this positive link has been provided through a variety of approaches, including (i) stock market reactions to environmentally positive or negative events (e.g., Klassen and McLaughlin 1996); (ii) regressions using emissions data (e.g., Hart and Ahuja 1996, King and Lenox 2001), environmental rankings data (e.g., Russo and Fouts 1997), and survey data on the extent of environmental efforts by the firm (e.g., Dowell et al. 2000); and (iii) comparisons of "portfolios" of environmentally superior and inferior firms (e.g., Cohen et al. 1997).

The opposing view is that superior environmental performance suggests diversions from the fiduciary responsibility of management, which could erode shareholder value (Walley and Whitehead 1994). Using announcements of process- and product-related environmental initiatives, Gilley et al. (2000) find no overall effect of announced initiatives on stock market returns. Jacobs et al. (2010) examine stock market reactions to several categories of announcements of corporate environmental initiatives (CEIs) and environmental awards and certifications (EACs). They find positive, none, and negative reactions across the various CEI and EAC categories. In particular, they find negative market reaction to announcements of voluntary emissions reductions.

However, the relationship between environmental performance and firm economic performance has not been established for the regulatory context where emissions are strictly capped but firms have the flexibility to choose among different compliance levers, including grandfathered allowances. As exemplified earlier, the compliance options for utility firms regulated by the Acid Rain Program are typically expensive (Burtraw et al. 1998). Therefore, affected firms that exhibit superior environmental performance may have likely incurred costs beyond the level needed for compliance. Consequently, we expect that superior environmental performance would associate with negative firm market performance in our context. Thus, we hypothesize the following:

Hypothesis 3 (H3). *Better environmental performance in terms of the targeted pollutant associates with lower firm market performance.*

3. Data and Measures

In this section, we discuss our data sources and present the measures of interest. The years 2004 and 2006 were, respectively, the first and most recent years of complete data availability when our study was initiated (i.e., about a two- to three-year lag in data availability; the period 2004–2006 falls under Phase 2 of the Acid Rain Program). We focus on coal as an energy source because the vast majority of SO_2 emissions under the program result from coal-fired generating units (EPA 2007); the compliance levers discussed in §2 also pertain to coal-fired units. The data collection process involved identifying all coal-fired electricity generating *units* regulated by the Acid Rain Program at *sites* owned by publicly traded utility *firms* (because we are interested in firm market performance) during the period 2004–2006.

The EIA *Annual Electric Generator Report—Generator (Existing) Files* provide annual details of generating units in the United States. We first filtered out units that did not use coal as an energy source. Next, we filtered out units less than 25 MW_e in capacity because these units are not regulated by the Acid Rain Program (EPA 2010a). We then filtered out units not operated by publicly traded utility firms. Finally, we filtered out units that were out of service for an entire year because these units were not available for any electricity generation during the year; we also filtered out units that were newly introduced into service mid-year because our measures are on an annual basis. Out of the 54 total publicly traded utility firms, 36 used coal as the primary energy source (i.e., coal accounted for more than 50% of the firm's total electricity generated over 2004–2006) and were therefore significantly affected by the provisions of the program. A step-by-step outline of our data filtering process is included in the appendix.

Table 1 Summary of Data Sources (DS)

DS#	Data field(s)[a]	Data source and year(s)
1	Heat input, electricity generation	EIA-906/920: *Power Plant Report* (2004–2006)
2	FGD presence and sulfur removal efficiency	EIA-767: *Annual Steam-Electric Plant Operation and Design Data* (2004–2005); EIA-860 Schedule 6: *Annual Electric Generator Report, Schedule 6* (2007)
3	Grandfathered allowances, SO_2 emissions	EPA *Clean Air Markets—Data and Maps* (Online Database)
4	Nameplate capacity, generating unit age	EIA-860: *Annual Electric Generator Report—Generator (Existing) File* (2004–2006)
5	Retail price of electricity by state	EIA-861: *Annual Electric Power Industry Data* (2004–2006)
6	Clearing price of SO_2 allowances in EPA spot auction	EPA *Allowance Auction Results* (2004–2006)
7	Firm financial data	Compustat Database

[a]For DS# 1–4, data are reported at the generating unit level.

Our final data set includes 433 coal-fired electricity generating units at 218 sites in 2004, 437 units at 219 sites in 2005, and 417 units at 201 sites in 2006, owned by 36 publicly traded utility firms. Although the number of firms in our data set appears to be low, it should be noted that the total number of publicly traded firms subject to the provisions of the Acid Rain Program is 54. Our sample captures a sizeable segment of the electric utility industry; over the period 2004–2006, the generating units in our data set accounted for about 45% of all coal-fired electricity and 22% of the 12.1 billion MWh_e of total electricity produced in the United States (EIA 2011a). Further, the units in our data set emitted 60% of the 29.9 million tons of sulfur dioxide emissions allocated under the Acid Rain Program during the period 2004–2006 (EPA 2007).

The main measures of interest correspond to our model elements of compliance levers (at-source, end-of-pipe, and allowances), environmental performance, and firm market performance. Our data sources are summarized in Table 1 and our measures are summarized in Table 2. We aggregate generating unit or site-level data to the firm level for the purpose of our analysis; the formulas used for this aggregation are summarized under the "Calculation" column in Table 2.

3.1. Principal Compliance Levers

- *Subbituminous Coal Usage (SUB_COAL)*: Heat input from subbituminous coal as a percentage of total coal heat input. This measure captures the level at which low-sulfur coal is used (at-source pollution prevention).
- *Efficiency-weighted Flue Gas Desulfurization* (*GEN_FGD*): Efficiency-weighted indicator measure of end-of-pipe abatement, implying both the presence of FGD (end-of-pipe pollution control) as well as the sulfur removal efficiency of FGD. We use an efficiency-weighted measure because different FGD technologies have different sulfur removal efficiencies (Nolan 2000).
- *Grandfathered Allowances to Capacity Ratio* (*GR_ALLOW*): Ratio of SO_2 allowances grandfathered as per the provisions of the Acid Rain Program to nameplate capacity, measuring the extent to which grandfathered allowances cushion against pollution prevention or pollution control costs.

3.2. Other Compliance Levers

The three levers discussed above constitute the principal compliance mechanisms used by utility firms in Phase 2 of the Acid Rain Program (e.g., Ellerman 2003b). However, we investigated two additional pollution prevention levers for their relevance to the firms in our study, namely, using *cleaner energy sources* (other than coal) and *process improvement*.

To lower emissions, firms may shift generation from coal to a less polluting source (e.g., natural gas, hydroelectric, wind). However, for the period covered by our study, we find that the usage of coal was stable for the firms in our sample. For the United States as a whole, we find that coal-fired units were responsible for 49.8%, 49.6%, and 49.0% of the electricity generated in 2004, 2005, and 2006, respectively. This, coupled with coal being the most abundantly available and least expensive of all energy sources (EIA 2007a), suggests that switching from coal to cleaner fuels was not a widely used compliance method during the period of our study.

Process improvements arising from an improved understanding of process chemistry, improved materials of construction, and improved reliability can favorably affect the environmental performance of utilities (Rubin et al. 2004). However, prior literature suggests that "low-hanging fruit" (Hart and Ahuja 1996) in terms of easy improvements in both operational (process) performance and environmental performance relative to the costs of related efforts are typically exhausted earlier in time, and additional efforts require significant investments that may indeed detract from the fiduciary responsibility of management. To examine the validity of this assertion to our context, we conducted an interview with a Technology Planning Manager at the Southern Company—a major electric utility affected by the provisions of the Acid Rain Program (Massari 2010). From the interview we learned that (i) the pollution reductions resulting from process improvements in existing facilities are, in general, marginal in comparison to the reductions targeted by the program

Table 2 Summary of Measures, Calculations, and Data Sources

Measure	Abbreviation	Description	Calculation	Data source (DS#) from Table I	2004 Mean (std. dev.)	2005 Mean (std. dev.)	2006 Mean (std. dev.)
Subbituminous coal usage	*SUB_COAL*	Heat input from subbituminous coal as a percentage of total coal heat input	100 × (Firm's total heat input from subbituminous coal in million Btu) ÷ (Firm's total coal heat input in million Btu)	1	44% (41%)	44% (40%)	46% (40%)
Efficiency weighted flue gas desulfurization	*GEN_FGD*	Coal heat input from a firm's units employing FGD, as a percentage of total coal heat input	100 × (Unit's coal heat input in million Btu × I × FGD efficiency) summed over all units owned by the firm ÷ (Firm's total coal heat input in million Btu); $I = 1$ if FGD present at unit, 0 if not	1, 2	20% (31%)	33% (36%)	32% (37%)
Grandfathered allowances to capacity ratio	*GR_ALLOW*	Ratio of SO_2 allowances grandfathered to nameplate capacity	(Total number of SO_2 allowances grandfathered to the generating units owned by the firm) ÷ (Firm's total nameplate capacity in MW_e)	3, 4	26.1 (7.7)	26.7 (7.9)	26.6 (8.2)
Utilization of newer coal sites	*UTIL_NEW*	Ratio of electricity generated by sites at or below the firm's median site age, to the firm's total nameplate capacity	(Sum of generation in MWh_e at sites at or below the firm's median site age in years) ÷ (Firm's total nameplate generation capacity in MWh_e); site age calculated as the nameplate capacity-weighted average age of generating units at a site	1, 4	0.38 (0.17)	0.45 (0.19)	0.45 (0.18)
SO_2 emissions quotient	*EQ*	SO_2 emissions per unit of coal heat input	(Firm's total SO_2 emissions in pounds) ÷ (Firm's total coal heat input in million Btu)	1, 3	1.13 (0.68)	1.02 (0.56)	0.97 (0.61)
Tobin's *q*	*TOBIN_Q*	Firm's market value per dollar of replacement costs of assets	(Equity value + Book value of long-term debt + net current liabilities) ÷ (Value of total assets)	7	0.95 (0.17)	0.98 (0.20)	1.03 (0.19)
Average retail price of electricity	*EL_PRICE*	Average retail price of electricity in states where the firm's sites are located	(Average retail price/kWh in state where site is located × Site generation in MWh_e) summed over all sites owned by the firm ÷ (Firm's total generation in MWh_e)	1, 5	7.11 (1.65)	7.59 (1.90)	8.17 (2.06)
Allowance price	*PRICE_ALLOW*	Clearing price of SO_2 allowances	Clearing price of SO_2 allowances in the annual EPA spot auction ($)	6	260.00 (-)	690.00 (-)	860.07 (-)
Total firm assets	*ASSETS*	Firm size (assets)	Total firm assets ($)	7	16.3 (25.5)	16.7 (25.0) ($ billion)	17.8 (28.3)
Leverage	*LEVERAGE*	Ratio of debt to total firm assets	(Total long term debt ÷ Total assets)	7	0.36 (0.11)	0.33 (0.10)	0.32 (0.10)
Return on assets	*ROA*	Firm's earnings from capital assets	(Net income) ÷ (Total assets)	7	0.09 (0.03)	0.09 (0.04)	0.10 (0.04)
Return on sales	*ROS*	Firm's profit per dollar of sales	(Net income) ÷ (Sales)	7	0.22 (0.09)	0.20 (0.09)	0.23 (0.10)

Note. Firm/site totals/averages are arrived at by aggregating over the generating units considered in our sample.

and (ii) the most promising of these process improvement opportunities (e.g., improving combustion efficiencies of coal burners) were exhausted during the early stages of the program.

However, the Clean Air Act of 1990 mandates utility firms to utilize the Best Available Control Technology (BACT) when constructing new facilities, including "application of [best available] production processes or methods, systems, and techniques" (EPA 2010c). Thus, it is reasonable to expect that newer coal sites would be more likely to have improved processes relative to older coal sites and that a possible compliance lever for the firms in our sample would be to utilize newer sites to a greater extent. We therefore consider the variable *Utilization of Newer Coal Sites* (*UTIL_NEW*) as an additional compliance lever. We measure the age of a site as the nameplate capacity-weighted average age of generating units at the site; we define a newer site as a site of age at or below the median age of all sites owned by the same firm. We measure *UTIL_NEW* as the ratio of electricity generated by a firm's newer sites to the firm's total nameplate capacity.

3.3. Environmental Performance

We measure firm environmental performance (in terms of the targeted pollutant) as SO_2 *Emissions Quotient* (*EQ*), defined as the total number of pounds of SO_2 emitted per million Btu of total coal heat input (e.g., Ellerman et al. 1997) across the generating units owned by the firm. A lower *EQ* indicates better environmental performance.

3.4. Firm Market Performance

We use Tobin's q as the measure of firm market performance, which represents a firm's market value per dollar of replacement costs of tangible assets. Tobin's q is an important and widely accepted measure of corporate performance (e.g., Lindenberg and Ross 1981, Dowell et al. 2000, Hennessy 2004). As in Dowell et al. (2000), we measure Tobin's q as the sum of equity (end-of-year share price times the number of outstanding common shares), long-term debt, and net current liabilities divided by total assets.

3.5. Controls

A utility firm's performance is likely to be influenced by regulatory and firm-specific factors. We include four controls—two that account for regulatory influences and two that capture firm-specific financial effects. Investor-owned utilities are monitored and regulated by state utility commissions and the U.S. Federal Energy Regulatory Commission (FERC). Prices charged to customers generally reflect the utility's cost to produce or purchase power in addition to associated transmission fees, charges for ancillary services to increase reliability, and a regulated rate of return on assets (EIA 2007b). The inability of firms to fully dictate pricing may influence the operational decisions made by the firm (Hayashi et al. 1997). We therefore use *Average Retail Price of Electricity* (*EL_PRICE*) as a control that captures the potential effects of such regulation on the firms in our sample. We calculate *EL_PRICE* as the average retail price of electricity per kWh in states where the firm's sites are located, weighted by the sites' electricity generation. Additionally, because the value of allowances could be associated with the market performance of the firms in our study, we include the clearing price of SO_2 allowances in the annual EPA spot auction (*PRICE_ALLOW*) as a control.

We also include firm size and leverage as controls. We use total firm assets (*ASSETS*) as a measure of firm size (e.g., Dowell et al. 2000, King and Lenox 2002). We use leverage as a control because debt load could affect firm market performance (Capon et al. 1990, McConnell and Servaes 1995). We measure *LEVERAGE* as the ratio of debt to total firm assets. Table 2 summarizes the descriptions, calculations, data sources, and descriptive statistics of our measures.

4. Empirical Analysis

To test our hypotheses of the relationships among compliance levers, environmental performance, and firm market performance, we employ multivariate regressions. Specifically, as suggested in Figure 1, we employ a model wherein *Environmental Performance* acts as an intermediate construct (e.g., Hauser and Simmie 1981) in the relationship between *Operational Compliance Levers* and *Firm Market Performance*. In other words, compliance levers have a direct as well as an indirect relationship with firm market performance. Whereas the direct relationship captures the nonenvironmental effect of the compliance levers on firm market performance (e.g., through accompanying process changes), the indirect relationship stems from the effect of compliance levers on environmental performance, which has implications for firm market performance. The main *dependent variable* for our empirical analysis is firm market performance, measured as Tobin's q. The variables that explain variance in firm market performance include the *controls*—*EL_PRICE*, *PRICE_ALLOW*, *ASSETS*, and *LEVERAGE*; the *compliance levers*—at-source fuel switching (*SUB_COAL*), end-of-pipe scrubbing (*GEN_FGD*), grandfathered allowances (*GR_ALLOW*), and utilization of newer coal sites (*UTIL_NEW*); and *environmental performance* in terms of the targeted pollutant (*EQ*).

Recall that we limited our data set to the 36 publicly traded utility firms (over a three-year period 2004–2006) that used coal as the primary energy source. Nonetheless, we examined whether we could pool these 36 firms with the 18 other publicly traded utility firms and isolate the results for the firms of interest using a binary control variable. We performed a Wald test for our panel data models in a manner analogous to the Chow test of pooling employed in cross-sectional data analysis (Chow 1960, Han and Park 1989, Baltagi and Raj 1992, Greene 2003) to examine whether the distribution of parameters for the firms that used coal as the primary energy source is similar to the distribution of parameters for the other firms (null hypothesis). We performed two variations of the Wald test—one including the constant term and one excluding the constant term in the regressions. The respective chi-square test statistics in these variations are $\chi^2(10) = 309.03$ (with intercept; $p < 0.01$) and $\chi^2(9) = 342.24$ (without intercept; $p < 0.01$), thus rejecting the null hypothesis and indicating that the parameter distributions are very different for these subpopulations. We therefore focus our analysis on the 36 firms that used coal as the primary energy source.

4.1. Model Specification

Diagnostic tests indicated evidence of first order autocorrelation as well as heteroskedasticity across panels. Therefore, we estimate the regression coefficients using a cross-sectional time-series feasible generalized least squares (FGLS) specification (Kmenta 1986, Greene 2003). The FGLS procedure parsimoniously produces residuals that are used to estimate the unit-specific serial corrections of the error term, which in turn are used to transform the model into one with serially independent errors. Specifically, we employ a panel-specific autoregressive (AR(1)) specification. We performed a generalized Hausman test (suitable for small samples) using the "suest" procedure (seemingly unrelated estimation) in Stata, which suggested that an FGLS specification is suitable for our data.

We employ regression model (1) below with firm market performance (Tobin's q) as the dependent variable and model (2) below with environmental performance (EQ) as the dependent variable. We observe that our dependent and independent variables are not linearly related. The Box–Cox procedure indicated the appropriateness of log-log specifications for our data (Box and Cox 1964, Greene 2003).

3We sequentially introduce sets of our independent variables and examine the coefficients of the main explanatory factors (e.g., Cachon and Olivares 2010). We first estimate Tobin's q as a function of firm-level controls identified in the literature (e.g., Capon et al. 1990, Hayashi et al. 1997, Dowell et al. 2000). We subsequently introduce compliance levers and environmental performance to examine their coefficients and incremental explanatory powers. Overall, we estimate the parameters using the following two simultaneous regression models:

Firm Market Performance

= f(Control Variables, Compliance Levers,

and Environmental Performance);

$$\begin{aligned}\log(TOBIN\_Q_{it}) &= \beta_0 + \beta_1 \log(EL\_PRICE_{it}) + \beta_2 \log(ASSETS_{it}) \\ &\quad + \beta_3 \log(LEVERAGE_{it}) + \beta_4 \log(SUB\_COAL_{it}) \\ &\quad + \beta_5 \log(GEN\_FGD_{it}) + \beta_6 \log(GR\_ALLOW_{it}) \\ &\quad + \beta_7 \log(UTIL\_NEW_{it}) + \beta_8 \log(PRICE\_ALLOW_{it}) \\ &\quad + \beta_9 \log(EQ_{it}) + \varepsilon_{1it} \qquad (1)\end{aligned}$$

Environmental Performance = f(Compliance Levers);

$$\begin{aligned}\log(EQ_{it}) &= \mu_0 + \mu_1 \log(SUB\_COAL_{it}) + \mu_2 \log(GEN\_FGD_{it}) \\ &\quad + \mu_3 \log(GR\_ALLOW_{it}) + \mu_4 \log(UTIL\_NEW_{it}) \\ &\quad + \varepsilon_{2it} \qquad (2)\end{aligned}$$

Table 3 **Parameter Estimates for FGLS Panel Regression; Dependent Variable: Firm Market Performance (Tobin's *q*)**

Variable	Parameter	Step 1	Step 2	Step 3
Intercept	β_0	1.540***	1.764***	1.694***
		(0.079)	(0.103)	(0.103)
Firm-level controls				
log(*EL_PRICE*)	β_1	−0.008	−0.142***	−0.168***
		(0.018)	(0.032)	(0.024)
log(*ASSETS*)	β_2	−0.038***	−0.048***	−0.044***
		(0.003)	(0.003)	(0.003)
log(*LEVERAGE*)	β_3	0.068	0.147***	0.193***
		(0.043)	(0.042)	(0.043)
Compliance levers				
log(*SUB_COAL*)	β_4		−0.067***	−0.035**
			(0.014)	(0.017)
log(*GEN_FGD*)	β_5		−0.043***	−0.024**
			(0.008)	(0.012)
log(*GR_ALLOW*)	β_6		0.021	−0.008
			(0.016)	(0.016)
log(*UTIL_NEW*)	β_7		0.085***	0.072***
			(0.019)	(0.023)
Allowance price				
log(*PRICE_ALLOW*)	β_8		0.034***	0.041***
			(0.005)	(0.004)
Environmental performance				
log(EQ)	β_9			0.075***
				(0.017)
Model fit: χ^2		155.34***	398.05***	680.00***
p-value		0.000	0.000	0.000

Note. Standard errors are shown in parentheses.
$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Note that i in the regression equations above represents the index for firms and t represents the index for time periods (years). Results for the firm market performance model are presented in Table 3, and results for the environmental performance model are shown in Table 4.

Table 4 **Parameter Estimates for FGLS Panel Regression; Dependent Variable: Environmental Performance (SO_2 Emissions Quotient, *EQ*)**

Variable	Parameter	Coefficient
Intercept	μ_0	0.792***
		(0.090)
log(*SUB_COAL*)	μ_1	−0.561***
		(0.029)
log(*GEN_FGD*)	μ_2	−0.478***
		(0.040)
log(*GR_ALLOW*)	μ_3	0.063**
		(0.027)
log(*UTIL_NEW*)	μ_4	−0.093**
		(0.041)
Model fit: χ^2		590.52***
p-value		0.000

Note. Standard errors are shown in parentheses.
$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

4.2. Explanatory Power of Key Model Elements

Starting with a base model with firm-level controls that explain Tobin's q (Step 1 in Table 3), we include our main independent variables in an incremental manner to tease out the effects of compliance levers and environmental performance on firm market performance. We use Wald tests to assess the statistical significance of each set of variables (Greene 2003). For the variables introduced in Step 2, we observe that the compliance levers jointly explain firm market performance ($\chi^2(4) = 179.19$; $p < 0.01$). In the next step (Step 3), we include the environmental performance variable (with compliance levers already included in the regression model) and find that environmental performance significantly explains firm market performance ($\chi^2(1) = 18.46$; $p < 0.01$). Thus, we find that the set of compliance levers as well as environmental performance have statistically significant explanatory power in our firm market performance model. Further, we find that superior environmental performance (i.e., lower *EQ*) is significantly associated with *lower* firm market performance.

Next, we perform several tests (Judd and Kenny 1981, Baron and Kenny 1986, MacKinnon et al. 2002) to examine whether environmental performance acts as an intermediate construct in the relationship between compliance levers and firm market performance. Results of these tests indicate that (a) the compliance levers are significantly associated with firm market performance, even after accounting for environmental performance and firm-level controls; (b) the relationship between environmental performance and firm market performance does not lose statistical significance in the full model where compliance levers and firm-level controls are simultaneously included; and (c) the compliance levers are significantly associated with environmental performance (H2A, HB, and HC; FGLS estimates are shown in Table 4).

4.3. Results

Overall, the joint tests of significance show strong statistical associations among the compliance levers (considered together), environmental performance, and firm market performance, consistent with the framework in Figure 1. Results of the FGLS panel model for firm market performance are summarized in Table 3. As seen in the full model (Step 3) in Table 3, the at-source and end-of-pipe levers (*SUB_COAL* and *GEN_FGD*) are significantly and negatively associated with Tobin's q (supporting H1A and H1B), whereas the utilization of newer coal facilities is significantly and positively associated with Tobin's q. However, we do not find support for the relationship between the level of grandfathered allowances and Tobin's q (H1C is not supported). Thus, the results in Table 3 show that both pollution prevention and pollution control efforts are significantly and negatively associated with firm market performance in our context. In other words, even pollution prevention efforts may be negatively associated with firm market performance when caps on emissions are strict—in contrast to the findings in the prior literature that do not take the regulatory environment into account. On the other hand, the shifting of generation to newer facilities employing improved processes appears to be an economically viable lever. However, this utilization strategy would require newer facilities to have excess capacity (e.g., if nameplate capacity is matched to peak demand) so that generation can be shifted toward them.

Table 4 includes estimates of the FGLS panel regression of environmental performance against the compliance levers. Consistent with the view in the established literature (see §2.2), we find that greater use of the at-source lever *SUB_COAL* associates with superior environmental performance (supporting H2A). Additionally, we find that the end-of-pipe lever *GEN_FGD* is significantly associated with improved environmental performance (supporting H2B). Interestingly, the magnitudes of the coefficients (which can also be interpreted as elasticities because we have log-log regression model specifications) suggest that for our context as well, pollution prevention is more effective than pollution control in explaining environmental performance; a chi-square test of the difference in the *SUB_COAL* and *GEN_FGD* coefficients yields $\chi^2(1) = 3.05$ at $p < 0.10$. In addition, the utilization of newer coal sites is significantly associated with lower emissions, thus providing evidence for the link between improved processes and superior environmental performance. Further, we find that from a public policy standpoint, a greater level of allowance grandfathering associates with lower environmental performance (supporting H2C). This suggests that when allowances are grandfathered, their tradability may not sufficiently incentivize firms to lower their emissions.

Finally, our firm market performance model (Table 3, Step 3) indicates a strong negative relationship between environmental performance (i.e., lower *EQ*) and Tobin's q, thus supporting H3. As for the control variables, we find that lower retail prices of electricity and higher allowance prices are associated with higher firm market performance. Although a higher allowance price intuitively implies a greater monetary value of grandfathered allowances, the finding for the retail price of electricity could be because of greater consumption levels at lower prices. We next discuss the results of various robustness tests.

4.4. Robustness Tests

Because the FGLS procedure could be sensitive to small sample sizes, we alternatively employ panel-corrected standard errors (PCSE) and find that the directions of the coefficients are consistent with our FGLS estimates. We also test the sensitivity of our regression estimates to the sample selection criterion of the share of coal in the firm's total electricity generated over 2004–2006. Our analysis and results presented so far are based on the sample of 36 firms where coal accounted for more than 50% of the firm's total electricity generated over 2004–2006. Our results are robust when the threshold for the share of coal is changed to 45% and 40%. For samples based on these thresholds, all coefficients and directions are consistent with those in Step 3 of Table 3; the only difference is that the statistical significance of the coefficient for *SUB_COAL* improves to $p < 0.01$ with the 40% threshold. Increasing the coal share threshold to, say, 55% or 60% limits the degrees of freedom for analysis due to nontrivial reductions in the sample size.

We conduct three additional analyses to investigate the robustness of our finding regarding the negative association between environmental performance and economic performance. First, although we are primarily interested in firm market performance because it reflects longer term value, we use accounting measures of firm economic performance—*ROA* and *ROS*—in place of Tobin's q and find that the statistical significances of the relationships in Figure 1 continue to hold. Further, consistent with the finding for Tobin's q in Step 3 of Table 3, we find that superior environmental performance is significantly associated with lower *ROA* and *ROS* ($\beta = 0.010$; $p < 0.01$ for EQ in the ROA model; $\beta = 0.083$; $p < 0.01$ for EQ in the ROS model).

Second, we examine the relationship between environmental performance and firm market performance across two-year and three-year lags. Specifically, we estimate (i) a two-year lag model where Tobin's q at time $t+2$ is regressed against environmental performance and firm-level controls at time t, with Tobin's q at times t and $t+1$ included as lagged firm market performance controls; and (ii) a three-year lag model where Tobin's q at time $t+3$ is regressed against environmental performance and firm-level controls at time t, with Tobin's q at times t, $t+1$, and $t+2$ included as lagged firm market performance controls. For the two-year lag model, the coefficient for EQ is positive and significant at $p < 0.01$ ($\beta = 0.086$; t-statistic of 3.01). The coefficient for EQ is also positive and significant at $p < 0.01$ for the three-year lag model ($\beta = 0.113$; t-statistic of 2.68). These results suggest that the association between superior environmental performance and lower firm market performance persists over a three-year period.

Table 5 Summary of Hypotheses and Findings

Hypothesis	Statement	Supported?
H1A[a]	Greater use of an at-source lever associates with lower firm market performance.	Supported
H1B[a]	Greater use of an end-of-pipe lever associates with lower firm market performance.	Supported
H1C[a]	A greater level of allowance grandfathering associates with better firm market performance.	Not supported
H2A	Greater use of an at-source lever associates with better environmental performance in terms of the targeted pollutant.	Supported
H2B	Greater use of an end-of-pipe lever associates with better environmental performance in terms of the targeted pollutant.	Supported
H2C	A greater level of allowance grandfathering associates with lower environmental performance in terms of the targeted pollutant.	Supported
H3	Better environmental performance in terms of the targeted pollutant associates with lower firm market performance.	Supported

[a]The *joint* effect of compliance levers is significant in the model with Tobin's q as the measure of firm economic performance as well as in the robustness check models with *ROA* and *ROS* as alternative measures of economic performance.

Third, to consider a relative measure of firm market performance, we replace the Tobin's q *values* with relative *ranks* in each year. In multivariate PCSE regression (used instead of FGLS because of the limited variance in the rankings across years) of this ranked measure against the independent variables in Step 3 of Table 3, we find that firms with lower environmental performance have higher relative market performance (slope $= 5.457$; $p < 0.05$ for the EQ-firm market performance (ranked) relationship).

Further reflections on our results follow in §6. Table 5 includes a summary of our hypotheses and findings.

5. Discussion

Our results for the context of a stringent yet flexible cap and trade program with the policy concession of allowance grandfathering indicate a significant relationship between better environmental performance and lower economic performance for affected firms at least over a three-year period. By explicitly considering the context of stringent regulation, we find a counter-example to the view that better environmental performance generally associates with better economic performance. Our findings suggest that affected firms that leverage the flexibility and generosity afforded by a cap and trade program with allowance grandfathering and adopt compliance strategies that do not overambitiously attempt to reduce emissions are associated with better economic performance at least in the shorter term.

From a regulatory perspective, our results show a significant and negative association between allowance grandfathering and firm environmental performance. Environmental regulation worldwide has been advancing in the direction of tradable allowance programs with allowances being grandfathered to incumbents based on historical benchmarks. However, the tradability of allowances does not guarantee that firms will strive to operate cleanly. We hope our empirical findings will contribute to the existing debate as to whether allowances should in fact be grandfathered. Among the arguments in favor of auctioning allowances as opposed to grandfathering them are superior incentives for environmental innovations and greater liquidity in allowance markets (Stavins 1998, Cramton and Kerr 2002).

The favorable results associated with higher utilization of newer coal sites are unique among the compliance levers examined in our study; this is the only lever for which a higher adoption level is associated with improved environmental and market performance. On a short-term basis, considerations such as baseload supply requirements, efficient load factors, and ramp up times may limit the extent to which generation can be shifted between sites. However, if capital expansions are known to be long-drawn (as is the case in the electric utility industry), a strategic way to enable favorable environmental and market outcomes into the future could be to design facilities employing state-of-the-art processes (either voluntarily or under regulatory requirements such as BACT) with capacity cushions that would enable generation to be shifted toward them.

A caveat to generalizing our findings is that although we controlled for certain industry-specific aspects, the nature of the electric utility industry could be playing a role. First, the electric utility industry, by its very nature, is capital intensive, as are the accompanying environmental investments (Edison Electric Institute (EEI) 2009). Although we employ Tobin's q as a longer-term measure of a firm's economic performance, it could be several years before capital expansions take shape and investments are fully paid for. It is possible that the market overall may be using a large discount factor, thus penalizing significant and near-term capital investments. Apart from the market's discounting of monetary flows, it is also possible that the market may be discounting a future regulatory disruption that may indeed benefit cleaner firms (e.g., impending air toxics standards for coal-fired generating units; EPA 2011). Second, only some states have deregulated the retail pricing of electricity, whereas utilities in other states have to negotiate rate schedules (EIA 2007b). The latter utilities might take longer to recoup the costs of environmental investments. A possible way to account for the above factors in future research would be to examine the market performance of the utility firms well beyond the three years we were able to consider in our robustness test in §5. Third, we note that there exist other avenues for utility firms to improve their economic performance beyond cost-effective environmental compliance. These include choosing appropriate financing vehicles for capital investments and focusing on operations and maintenance budgets (EEI 2009). Although outside of the scope of our study, these avenues may also be deserving of managerial attention.

The years 2004–2006 were the only years of complete data availability when this study was initiated (about a two- to three-year lag in data availability). As discussed in §3, switching from coal to a less polluting fuel, such as natural gas, was not widely used as a compliance lever during this period. However, in recent years, the share of coal in electricity generation has been decreasing in comparison to the share of natural gas; e.g., the share of coal decreased 1% from November 2009 to November 2010, compared to an 8% increase in the share of natural gas, attributable to the decrease in the price of natural gas (EIA 2011b). As more years of data become available, our study could be extended to capture other viable compliance levers. Further, the period covered by our study also represents a period of stability in the emissions levels permitted under the Acid Rain Program. As per the provisions of the program, the annual SO_2 emissions cap was reduced from 9.5 million to 8.95 million tons in 2010, the first such decrease in 10 years (EPA 2010c). It will be purposeful to conduct longitudinal assessments of the relationship between firm environmental and economic performance under conditions of tightening regulation.

Finally, the generalizability of our findings can best be tested as other cap and trade programs—such as the EU Emissions Trading Scheme (ETS) for greenhouse gases—evolve and mature. However, we believe that our findings are likely to hold for stringent programs employing allowance grandfathering. In complying with cap and trade programs in general, firms are likely to have at-source and end-of-pipe compliance options similar in character to those modeled in this study, together with the use of allowances. Thus, in broader terms, we hope this study will be of value both to firms as well as policy makers participating in market-based regulation for capping emissions.

6. Conclusion

A premise for our hypothesized relationships is the significant costs relative to the economic benefits involved in environmental investments. In certain instances where an industry or pollutant is subject to environmental regulation that is at its infancy (in contrast to the Acid Rain Program that has been in place for more than 15 years), it is possible that firms affected by such regulation might in fact obtain productivity gains or "innovation offsets" in the sense of Porter and van der Linde (1995) by undertaking relatively inexpensive initiatives to reduce pollution. It will be worthwhile to examine the relationship between firms' environmental and economic performance in such a context and contrast the findings to those in our study.

The nature of the pollutant may play a role in the suitability or effectiveness of a cap and trade program. For example, and in contrast to SO_2, CO_2 is a "uniformly mixed accumulative pollutant," implying that the environmental impact is irrespective of the location or the timing of emissions. CO_2 has therefore been regarded as a superior candidate for cap and trade because legislation can conveniently focus on overall emissions, with emission "hot spots" being less problematic (Cramton and Kerr 2002, Burtraw et al. 2005). On the flip side, CO_2 regulation must ideally be cross-regional to limit free-riding. Even if a cross-regional program is in place, the monitoring of CO_2 emissions is challenging because of the scores of stationary and moving sources (Fischer et al. 1998, Colby 2000). The EU ETS was phased in starting with the most energy intensive sources such as combustion plants, iron and steel plants, and factories manufacturing cement and paper. For these sources, the available compliance levers beyond energy efficiency are similar to those captured in our study, namely, at-source fuel switching (e.g., coal to natural gas), end-of-pipe abatement (e.g., CO_2 separation or sequestration), and the use of allowances to account for emissions (EIA 1998, Springer and Varilek 2004). However, current technologies to separate CO_2 from the emissions stream are expensive and yet to mature (Herzog and Golomb 2004).

Another flexible regulatory alternative is a tax on emissions. Applying an analogous reasoning for the context of a stringent tax, we hypothesize that both at-source as well as end-of-pipe levers will have to be tapped into by the firm in order to keep emissions and tax liabilities low. Economists have shown that for every industry *cap* on emissions, there is an equivalent *tax* that can theoretically achieve the same overall emissions (e.g., Requate 1993). However, cap and trade regulation legislates the ultimate goal of capping industry emissions as compared to taxes that may not guarantee that an intended emissions goal will in fact be realized. We conjecture that our hypotheses of the relationships among at-source and end-of-pipe levers, environmental, and firm market performance would be similar with stringent taxes. However, a key facet of cap and trade programs that does not feature under taxes is emissions allowances; the allocation of these allowances has a bearing on firms' environmental and economic performance.

In conclusion, we note that our findings should not be misconstrued as a criticism of cap and trade programs. The U.S. Acid Rain Program's achievement of substantially reducing SO_2 emissions levels is testament to the program's success (Burtraw and Palmer 2004). However, from a firm's perspective, our evidence suggests that firms regulated under a stringent cap and trade program may not be rewarded by the market for superior environmental performance (at least for a three-year period). Also, the grandfathering of emissions allowances may diminish the incentive for firms to be clean even if the allowances are freely tradable. Therefore, we wish to direct the findings of this study toward a continuing discussion of incentives under and potential improvements over current implementations of cap and trade regulation.

Acknowledgments

The authors gratefully acknowledge the exceptional and timely reviews received from the three anonymous referees, the associate editor, and the editor-in-chief.

Appendix. Data Filtering Process

Data: Form EIA-860, "Annual Electric Generator Report"—Generator (Existing) File (2004 to 2006)

Available at http://www.eia.gov/cneaf/electricity/page/capacity/capacity.html

Form EIA-860 is a survey that includes detailed information about generating units and environmental equipment at electric power plants with ≥1 MW_e combined nameplate capacity.

2004: 16,770 units
2005: 16,808 units
2006: 16,924 units

↓

Step 1: Filter out units not using coal as a fuel source (vast majority of SO_2 emissions under the Acid Rain Program are from coal-fired units).

2004: 1,526 units remain
2005: 1,522 units remain
2006: 1,493 units remain

↓

Step 2: Filter out units < 25 MW_e (not regulated by Acid Rain Program).

2004: 1,148 units remain
2005: 1,154 units remain
2006: 1,142 units remain

↓

Step 3: Filter out units not operated by a publicly traded utility firm (dependent variable of interest is firm market performance).
2004: 844 units remain
2005: 825 units remain
2006: 827 units remain

↓

Step 4: Filter out units out of service (units not available for generation) or not online at the start of the year (our measures are on an annual basis).
2004: Removed 7 units; 837 units remain*
2005: Removed 13 units; 812 units remain**
2006: Removed 13 units; 814 units remain***

*These 7 units were out of service during 2004, 2005, and 2006
**An additional 5 units were out of service in 2005 and 2006; 1 unit was newly commissioned in mid-2005.
***An additional 1 unit was out of service in 2006.

↓

Step 5: Aggregate units by site and utility firm.
2004: 54 publicly traded utility firms with 336 sites operating 837 units
2005: 54 publicly traded utility firms with 326 sites operating 812 units
2006: 54 publicly traded utility firms with 328 sites operating 814 units

↓

Step 6: Filter out firms where coal accounted for <50% of electricity generated during 2004–2006 (to focus on firms primarily affected by the provisions of the Acid Rain Program).
2004: 36 publicly traded utility firms with 218 sites operating 433 units remain
2005: 36 publicly traded utility firms with 219 sites operating 437 units remain
2006: 36 publicly traded utility firms with 201 sites operating 417 units remain

References

American Electric Power. 2003. Why SCRs at Gavin? Accessed July 2010, http://web.archive.org/web/20060322114715/http://www.aep.com/environmental/emissioncontrol/cleanenergy/docs/gavinscr1.ppt.

Angell, L. C., R. D. Klassen. 1999. Integrating environmental issues into the mainstream: An agenda for research in operations management *J. Oper. Management* **17**(5) 575–598.

Ball, J. 2008. Wall Street shows skepticism over coal—Banks push utilities to plan for impact of emissions caps. *Wall Street Journal* (February 4) A6.

Baltagi, B. H., B. Raj. 1992. A survey of recent theoretical developments in the econometrics of panel data. *Empirical Econom.* **17**(1) 85–109.

Baron, R. M., D. A. Kenny. 1986. The moderator-mediator distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Personality Soc. Psych.* **51**(6) 1173–1182.

Box, G., D. Cox. 1964. An analysis of transformations. *J. Royal Statist. Soc.: Ser. B* **26**(2) 211–264.

Burtraw, D., E. Mansur. 1999. Environmental effects of SO_2 trading and banking. *Environment. Sci. Tech.* **33**(20) 3489–3494.

Burtraw, D., K. Palmer. 2004. SO_2 cap-and-trade program in the United States: A "living legend" of market effectiveness. W. Harrington, R. Morgenstern, T. Sterner, eds. *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe*. Resources for the Future, Washington, DC, 41–67.

Burtraw, D., D. A. Evans, A. Krupnick, K. Palmer, R. Toth. 2005. Economics of pollution trading for SO_2 and NO_x. *Annual Rev. Environment Resources* **30** 253–289.

Burtraw, D., A. Krupnick, E. Mansur, D. Austin, D. Farrell. 1998. Costs and benefits of reducing air pollutants related to acid rain. *Contemporary Econom. Policy* **16**(4) 379–401.

Business Wire. 2005. PSI energy reaches settlement on environmental plan. (December 14), http://www.businesswire.com/news/home/20051214005614/en/PSI-Energy-Reaches-Settlement-Environmental-Plan.

Cachon, G. P., M. Olivares. 2010. Drivers of finished goods inventory performance in the U.S. automobile industry. *Management Sci.* **56**(1) 202–216.

Capon, N., J. U. Farley, S. Hoenig. 1990. Determinants of financial performance: A meta-analysis. *Management Sci.* **36**(10) 1143–1159.

Carlson, C., D. Burtraw, M. Cropper, K. Palmer. 2000. Sulfur dioxide control by electric utilities: What are the gains from trade? *J. Political Econom.* **108**(6) 1292–1326.

Center for Energy and Environmental Policy Research (CEEPR), Massachusetts Institute of Technology (MIT). 2010. Accessed July 2010, http://web.mit.edu/ceepr/www/publications/emissions.html.

Chow, G. C. 1960. Tests of equality between sets of coefficients in two linear regressions. *Econometrica* **28**(3) 591–605.

Cohen, M., S. Fenn, J. Naimon. 1997. Environmental and financial performance: Are they related? Working paper, Vanderbilt University, Nashville, TN.

Colby, B. 2000. Cap-and-trade policy challenges: A tale of three markets. *Land Econom.* **76**(4) 638–658.

Corbett, C. J., R. D. Klassen. 2006. Extending the horizons: Environmental excellence as key to improving operations. *Manufacturing Service Oper. Management* **8**(1) 5–22.

Corbett, C. J., P. R. Kleindorfer. 2001. Environmental management and operations management: Introduction to part 1 (manufacturing and eco-logistics). *Production Oper. Management* **10**(2) 107–111.

Cramton, P., S. Kerr. 2002. Tradeable carbon permit auctions: How and why to auction not grandfather. *Energy Policy* **30**(4) 333–345.

Dowell, G., S. Hart, B. Yeung. 2000. Do corporate global environmental standards create or destroy market value? *Management Sci.* **46**(8) 1059–1074.

Edison Electric Institute. 2009. The financial crisis and its impact on the electric utility industry. Accessed July 2010, http://www.eei.org/ourissues/finance/Documents/Financial_Crisis_and_Industry.pdf.

Ellerman, A. D. 1998. Electric utility response to allowances: From autarkic to market-based compliance. Report 98-009, MIT CEEPR, Cambridge, MA.

Ellerman, A. D. 2003a. Ex post evaluation of tradable permits: The U.S. SO_2 cap-and-trade program. Report 2003-003, MIT CEEPR, Cambridge, MA.

Ellerman, A. D. 2003b. Lessons from phase 2 compliance with the U.S. Acid Rain Program. Report 2003-009, MIT CEEPR, Cambridge, MA.

Ellerman, A. D., P. L. Joskow, D. Harrison, Jr. 2003. Emissions trading in the U.S.: Experience, lessons, and considerations for greenhouse gases. Pew center on global climate change. Accessed July 2010, http://www.pewclimate.org/docUploads/emissions_trading.pdf.

Ellerman, A. D., R. Schmalensee, P. L. Joskow, J. M. Montero, E. M. Bailey. 1997. Emissions trading under the U.S. Acid Rain Program: Evaluation of compliance costs and allowance market performance. MIT CEEPR, Cambridge, MA.

Fischer, C., S. Kerr, M. Toman. 1998. Using emissions trading to regulate U.S. greenhouse gas emissions: An overview of policy design and implementation issues. *Natl. Tax J.* **51**(3) 453–464.

Gilley, K. M., D. L. Worrell, W. N. Davidson, A. El-Jelly. 2000. Corporate environmental initiatives and anticipated firm performance. *J. Management* **26**(6) 1199–1216.

Greene, W. 2003. *Econometric Analysis.* Prentice Hall, Englewood Cliffs, NJ.

Han, A. K., D. Park. 1989. Testing for structural change in panel data: Application to a study of U.S. foreign trade in manufacturing goods. *Rev. Econom. Statist.* **71**(1) 135–142.

Hart, S. L. 1995. A natural-resource-based view of the firm. *Acad. Management Rev.* **20**(4) 986–1014.

Hart, S. L., G. Ahuja. 1996. Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. *Bus. Strategy Environment* **5**(1) 30–37.

Hauser, J. R., P. Simmie. 1981. Profit maximizing perceptual positions: An integrated theory for the selection of product features and price. *Management Sci.* **27**(1) 33–56.

Hayashi, P. M., J. Y.-J. Goo, W. C. Chamberlain. 1997. Vertical economies: The case of U.S. electric utility industry, 1983–87. *Southern Econom J.* **63**(3) 710–725.

Hennessy, C. A. 2004. Tobin's *q*, debt overhang, and investment. *J. Finance* **59**(4) 1717–1742.

Herzog, H. J., D. Golomb. 2004. Carbon capture and storage from fossil fuel use. *Encyclopedia Energy* **1** 277–287.

Ingebretsen, M., W. Sweet. 2003. SO_2: Setting the best example. *IEEE Spectrum* **40**(1) 59–62.

Jacobs, B., V. R. Singhal, R. Subramanian. 2010. An empirical investigation of environmental performance and the market value of the firm. *J. Oper. Management* **28**(5) 430–441.

Joskow, P. L., R. Schmalensee, E. M. Bailey. 1998. The market for sulfur dioxide emissions. *Amer. Econom. Rev.* **88**(4) 669–685.

Judd, C. M., D. A. Kenny. 1981. Process analysis: Estimating mediation in treatment evaluations. *Eval. Rev.* **5**(5) 602–619.

King, A. A., M. J. Lenox. 2001. Does it *really* pay to be green? An empirical study of firm environmental and financial performance. *J. Indust. Ecology* **5**(1) 105–116.

King, A. A., M. J. Lenox. 2002. Exploring the locus of profitable pollution reduction. *Management Sci.* **48**(2) 289–299.

Klassen, R. D., C. P. McLaughlin. 1996. The impact of environmental management on firm performance. *Management Sci.* **42**(8) 1199–1214.

Klassen, R. D., D. C. Whybark. 1999. The impact of environmental technologies on manufacturing performance. *Acad. Management J.* **42**(6) 599–615.

Kmenta, J. 1986. *Elements of Econometrics*. MacMillan, New York.

Lindenberg, E. B., S. A. Ross. 1981. Tobin's *q* ratio and industrial organization. *J. Bus.* **54**(1) 1–32.

Linton, J. D., R. Klassen, V. Jayaraman. 2007. Sustainable supply chains: An introduction. *J. Oper. Management* **25**(6) 1075–1082.

MacKinnon, D. P., C. M. Lockwood, J. M. Hoffman, S. G. West, V. Sheets. 2002. A comparison of methods to test mediation and other intervening variable effects. *Psych. Methods* **7**(1) 83–104.

Majumdar, S. K., A. A. Marcus. 2001. Rules versus discretion: The productivity consequences of flexible regulation. *Acad. Management J.* **44**(1) 170–179.

Marcus, A., D. Geffen. 1998. The dialectics of competency acquisition: Pollution prevention in electric generation. *Strategic Management J.* **19** 1145–1168.

Massari, J. 2010. Personal interview with James Kroes, July 26.

McConnell, J. J., H. Servaes. 1995. Equity ownership and the two faces of debt. *J. Financial Econom.* **39**(1) 131–157.

McKinnon, J. D. 2007. Bush weighs range of emission caps. *Wall Street Journal* (July 23) A8.

Napolitano, S., J. Schreifels, G. Stevens, M. Witt, M. LaCount, R. Forte, K. Smith. 2007. The U.S. Acid Rain Program: Key insights from the design, operation, and assessment of a cap-and-trade program. *Electricity J.* **20**(7) 47–58.

Nolan, P. S. 2000. Flue gas desulfurization technologies for coal-fired power plants. BR-1709. Presentation, Coal-Tech 2000 International Conference, November 13–14, Babcock & Wilcox Company, Barberton, OH.

Porter, M. E., C. van der Linde. 1995. Toward a new conception of the environment-competitiveness relationship. *J. Econom. Perspect.* **9**(4) 97–118.

Requate, T. 1993. Pollution control in a Cournot duopoly via taxes or permits. *J. Econom.* **58**(3) 255–291.

Riley, J. T., ed. 2007. *Routine Coal and Coke Analysis: Collection, Interpretation, and Use of Analytical Data*. American Society for Testing Materials, West Conshohocken, PA.

Rooney, C. 1993. Economics of pollution prevention: How waste reduction pays. *Pollution Prevention Rev.* **3**(3) 261–276.

Rubin, E. S., M. R. Taylor, S. Yeha, D. A. Hounshell. 2004. Learning curves for environmental technology and their importance for climate policy analysis. *Energy* **29**(9–10) 1551–1559.

Russo, M. V., P. A. Fouts. 1997. A resource-based perspective on corporate environmental performance and profitability. *Acad. Management Rev.* **40**(3) 534–559.

Smith, A. E., J. Platt, A. D. Ellerman. 1998. The costs of reducing utility SO_2 emissions—Not as low as you might think. MIT CEEPR, Cambridge, MA.

Springer, U., M. Varilek. 2004. Estimating the price of tradable permits for greenhouse gas emissions in 2008–12. *Energy Policy* **32**(5) 611–621.

Stavins, R. N. 1998. What can we learn from the grand policy experiment? Lessons from SO_2 allowance trading. *J. Econom. Perspect.* **12**(3) 69–88.

Taylor, R. 2009. Cap and trade. *Risk Management* **56**(8) 18–19.

Taylor, M., E. Rubin, D. Hounshell. 2005. Regulation as the mother of invention: The case of SO_2 control. *Law and Policy* **27**(2) 348–378.

U.S. Energy Information Administration (EIA). 1998. Impacts of the Kyoto protocol on U.S. energy markets and economic activity. Report SR/OIAF/98-03, U.S. Department of Energy, Washington, DC.

U.S. Energy Information Administration (EIA). 2007a. International energy outlook: 2007. U.S. Department of Energy, Washington, DC.

U.S. Energy Information Administration (EIA). 2007b. Residential electricity prices: A consumer's guide. Brochure DOE/EIA-X042, U.S. Department of Energy, Washington, DC.

U.S. Energy Information Administration (EIA). 2010. EIA-767 data files. U.S. Department of Energy, Washington, DC. Accessed June 2010, http://www.eia.doe.gov/cneaf/electricity/page/eia767/.

U.S. Energy Information Administration (EIA). 2011a. Electric power annual: Table ES1—Summary statistics for the United

States, 1998 through 2009. U.S. Department of Energy, Washington, DC. Accessed June 2011, http://205.254.135.24/cneaf/electricity/epa/epates.html.

U.S. Energy Information Administration (EIA). 2011b. Electric power monthly February 2011. DOE/EIA-0226 (2011/02), U.S. Department of Energy, Washington, DC.

U.S. Environmental Protection Agency (EPA). 1998. Final rule for 1998 reallocation of allowances. 63 FR 51705. EPA, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2002. Clearing the air: The truth about capping and trading emissions. EPA, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2003. Air pollution control technology fact sheet. EPA, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2007. Acid Rain Program: 2006 progress report. EPA, Washington, DC.

U.S. Environmental Protection Agency (EPA). 2010a. Acid Rain Program SO_2 allowances fact sheet. Accessed December 2010, http://www.epa.gov/airmarkets/trading/factsheet.html.

U.S. Environmental Protection Agency (EPA). 2010b. Cap and trade around the globe. Accessed January 2010, http://www.epa.gov/captrade/international.html.

U.S. Environmental Protection Agency (EPA). 2010c. Technology transfer network: Clean air technology center—RACT/BACT/LAER Clearinghouse. Accessed June 2010, http://www.epa.gov/ttn/catc/rblc/htm/welcome.html.

U.S. Environmental Protection Agency (EPA). 2011. Clean air mercury rule. Accessed June 2011, http://www.epa.gov/air/mercuryrule/.

U.S. Federal Energy Regulatory Commission (FERC). 2004. FERC form 423 annual data: Monthly report of cost and quality of fuels for electric plants 2004. FERC, Washington, DC.

Walley, N., B. Whitehead. 1994. It's not easy being green. *Harvard Bus. Rev.* (May–June) 46–52.

Yale Environment 360. 2009. Putting a price on carbon: An emissions cap or a tax? (May 7), http://e360.yale.edu/content/feature.msp?id=2148.