ENVIRONMENTAL REGULATIONS AND MARKET COMPETITIVENESS: SOME EMPIRICAL EVIDENCE FROM ELECTRIC UTILITIES

by

Anthony Rivera Raneses

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APPROVED:

Dr. Nancy A. Wentzler, Chair

Dr. William R. Porter

Dr. Brian Reid

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Anthony Rivera Raneses

Committee Chair: Professor Nancy A. Wentzler

Department of Economics

ABSTRACT

There has been a recurring debate on whether or not environmental regulations indirectly affect a firm's cost structure by motivating it to engage in technological innovation. Accordingly, innovation would eventually play a key role in a firm's market competitiveness or profitability. The Porter hypothesis therefore presents an interesting paradigm that through regulatory impetus, firms can be motivated to pursue innovation and strengthen it's market performance. However, opponents of the Porter hypothesis argue that increasing the stringency of regulations does not necessarily equate to greater profitability.

This paper tests the Porter hypothesis by using an augmented version of Repetto's model. The empirical results show that while the sign of the correlation coefficients tend to validate those of the Porter hypothesis, the association between environmental and economic performance is either subject to a spurious correlation problem when they are significant or is insignificant even when the effects of extraneous variables are netted out.

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I. INTRODUCTION

The recent literature on domestic environmental regulations stems from an academic debate covering an international scope. Since the 1991 U.N. Summit on the Environment, there has been a recurring argument on whether or not increasing environmental regulations benefit or harm countries engaging in free trade. For instance, Daly (1993) argued that countries need to continually increase environmental standards because, without it, free trade could hurt the environment. He also points out that regulations may induce countries to engage in technological innovation that would reduce production cost of countries' good and services. However, Baghwati (1993) argues against having more environmental regulations and stresses that increasing the stringency of standards only leads to an increase in compliance costs. For his part, Baghwati suggests that with the cost savings from less regulations, country governments would use their discretion to address other pressing problems they see fit (e.g. environmental protection, research and development (R&D), safe drinking water, job programs, etc.). Since Daly and Baghwati's articles, several theories emerged on the role of domestic environmental regulations and how it affects firm efficiency.

The Porter hypothesis

The Porter hypothesis is one conjecture which upholds the role of domestic regulations on the ability of firms to engage in technological innovation thus improving their cost structure (Porter and van der Linde, 1995; Porter, 1992 and 1994). It stems from the assumption that when firms are faced with imperfect information, they tend to be irrational-profit maximizing agents. Thus, the Porter hypothesis assumes that if there were several production technologies, a firm would not be able realize the "best" technology path without the impetus from regulatory action. As Porter and van der Linde states, "regulation signals firms about likely resource inefficiencies and potential technological improvements" (Porter and van der Linde, p. 101). Hence, with the "right" technology path due to properly-designed environmental standards, such innovation avenues may partially or more than fully offset the regulatory cost of complying them.

While the Porter hypothesis assumes that regulatory action would spur innovation among firms thus reducing their cost structure, it also considers that such innovation would increase a firm's competitive edge in the market. Porter and van der Linde defines market competitiveness--"the ability to sell in conjunction with local or foreign producers"--as a dynamic concept in that it stems from innovation--"a product's or service's design, the segment it serves, how it is produced, marketed, and supported." Even some supporters of the Porter hypothesis suggest that perhaps profitability is a better proxy than market competitiveness in that it better represents a firm's economic performance. These innovation and competitiveness enhancement effect of environmental regulations were seriously challenged by economists in the literature.

The debate

Based on neoclassical economics, Palmer et. al (1995) dispute the technological change impact of the environmental regulations. They maintain that since firms are always trying to be maximizing profits, they tend to be efficient. According to Palmer et. al, firms would not invest in research and development (R&D) unless it is worth to the firm to do so. Even when it is worth to the firm to engage in R&D, it is not clear that firms can be profitable. They illustrate this example in Figure 1 by depicting a hypothetical firm as a supplier of air quality. Cost schedules for pollution abatement are MAC1 and MAC2 and effluent fee P is the market-clearing price of emissions.

Figure 1 depicts that even when it is worth to the firm to engage in R&D, it is not clear that the firm would be profitable. The firm profit maximizes at a point where marginal benefit of regulations (assuming flat demand curve equals the effluent fee P) and marginal abatement cost of regulations (supply curve) connect. The firm is initially at marginal abatement cost MAC1 and produces output level A and faces effluent fee P. To move to MAC2, the cost of R&D effort to reduce to MAC2 must accordingly exceed the gains to the firm. Hence, it is not worthwhile to the firm to be away from B since B is the optimal point--the only point where the firm maximizes profits. The total gains to the polluting firm from undertaking the R&D is area OFCB. If regulators introduce a higher effluent fee standard of P', no one knows if the firm will respond to the higher fee by using the old technology at H or investing in a new one at D.

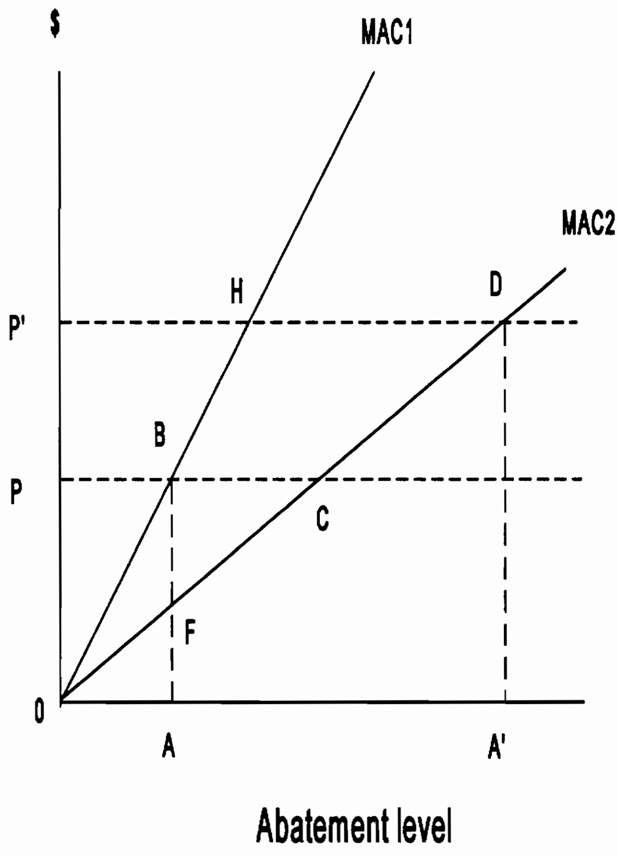

Figure 1: Supply function approach (Palmer et. al, 1996).

Palmer et. al prove that profits could not be any greater anywhere else than at the optimal point B. By geometric transitivity, Palmer et. al show that since profits at B is greater than at C, and at C is greater than at D, then a higher effluent fee implies less profits, no matter if the firm could invest in new abatement technology. Figure 2 also shows that a higher effluent fee e2 would not necessarily result to positive profits even when it is worth to the firm to shift from MAC1 to MAC2. Similar to this supply function approach, a profit function approach which analyzes the effect of environmental regulations on profitability is presented in Appendix A.

In the spirit of Palmer et. al, several previous papers also dispute the basic premise of the Porter hypothesis. Jorgenson and Wilcoxen (1990) show in a general equilibrium framework the negative effects of environmental regulations on U.S. economic growth. Likewise, Hazilla and Kopp (1990) examine the sizeable social cost of environmental quality regulations using a general equilibrium model. But more recently, Jaffe, Peterson, Portney, and Stavins (1995) portray that *ceteris paribus*, the impact of environmental regulations on the competitiveness of U.S. manufacturing is small, thus refuting the Porter hypothesis. While Palmer et. al have their own supporters, so does the Porter hypothesis.

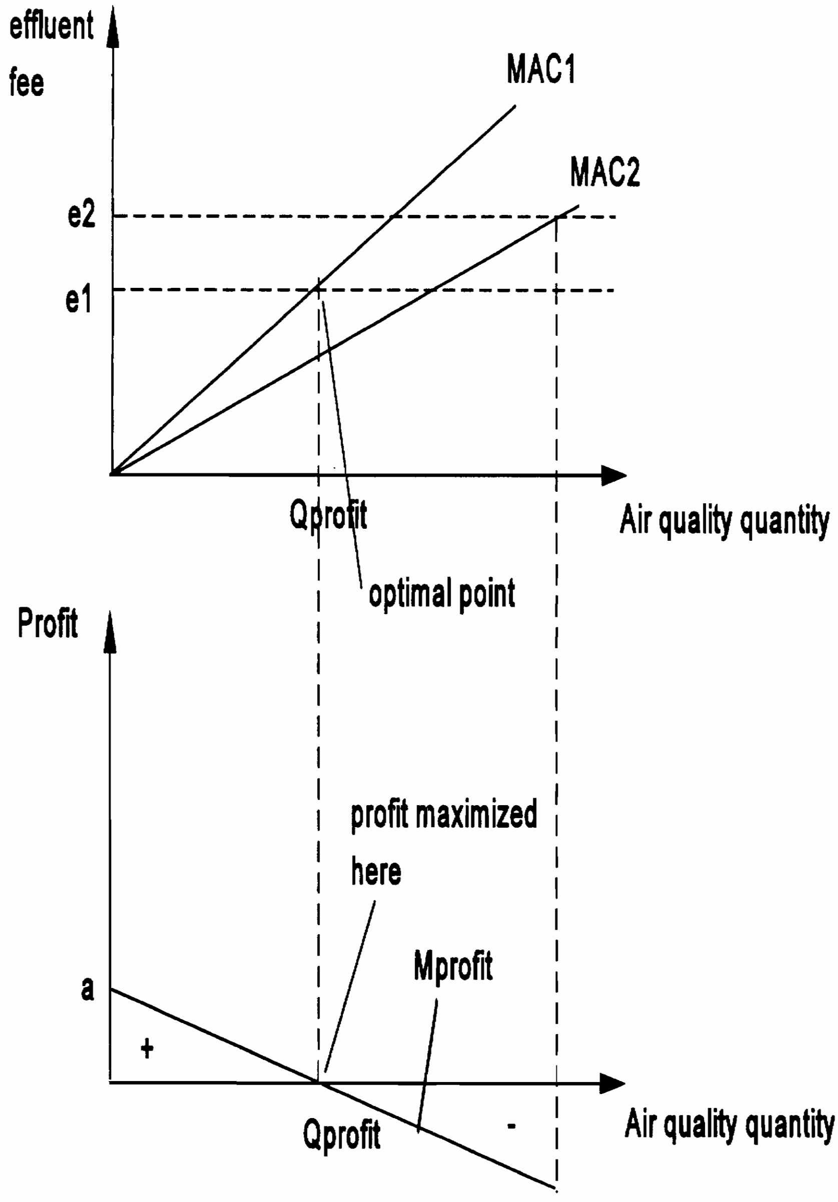

Figure 2: Case of higher effluent fees, R&D, and firm profits.

Bezdek (1993), Cohen et. al (1995), and Repetto (1995) directly or indirectly validate the Porter hypothesis through the use of case studies. Bezdek compares and contrasts the theoretical, anecdotal, and empirical evidence of environmental regulations and their so-called positive implication on the U.S. labor market. Cohen et. al use historical data on environmental and financial performance to show how "green" investors do not pay a premium for their environmental convictions. For instance, they find that companies that strive to maintain a sound environmental performance gain a financial advantage over competitors. In a more comprehensive study conducted by the World Resources Institute, Repetto (1995) uses Bureau of Census data by product SIC code to obtain a profit index. He then employs the Toxic Release Inventory (TRI) data provided by the Environmental Protection Agency (EPA) and estimates that the correlation between environmental performance, the ratio of bad (e.g. sulfur emissions) to good outputs (e.g. electricity), and market competitiveness (profit index), is negative thus promoting the Porter hypothesis.

Objectives

The objective of this paper is to be able to use Repetto's model in order to determine if those electric utilities that are classified by Congress as heavy emitters are more or less profitable and efficient than their counterparts in the industry. The main difference between Repetto's analysis and those of this paper is the selection criteria of the data. For his part, Repetto tests the Porter hypothesis in the possibility that firms with superior environmental performance also achieve superior profits within their industries. He chooses those firms by product SIC code that have exceptional environmental performance and correlates them with profitability. This paper, however, is concerned with the possibility that the Acid Rain Program of the Clean Air Act Amendment of 1990 (CAAA90) is associated with the profitability and cost structure of these heavy emitters (also known as Phase I compliance units).

To accomplish the objective of this paper, Chapter II discusses why firms maintain an environmental performance category and how it is measured. Chapter III relates how Repetto's simple and partial correlations test relates to the theoretical underpinnings of the Porter hypothesis by applying the model into two periods: before and after CAAA90. Chapter III then compares and contrasts correlation results of the two periods to show if the relationship between environmental performance and profitability, and more importantly, cost structure, improved or deteriorated after the Acid Rain Program was promulgated. Chapter IV concludes the paper and makes some recommendations.

II. CONCEPTUAL FRAMEWORK

What determines a firm's environmental performance?

A firm's environmental performance can be categorized into three levels: regulatory-driven, market-driven, and precautionary behavior-driven. First, firms react to regulations in various performance levels. The firm can, however, face or evade those regulations by either performing poorly or badly. Second, firms may be wary on consumer reaction to their products. For instance, if consumers are willing to pay for environmentally-sensitive products (e.g. recycled paper, biodegradable plastics, etc.) such that firms are finding profitable opportunities, then this could encourage better environmental performance among firms. Third, environmental performance could also depend on the precautionary behavior of firms to avoid the implied uncertainty of future regulatory compliance cost.

There is an extensive literature on mandatory pollution regulations. For instance, in the literature of the second-best theory of pollution regulation, the key concern is to solve for the optimal combination of enforcement and punishment upon opportunistic offenders. Second-best is the situation of an imperfectly enforceable pollution regulation which examines the effectiveness of major policy tools for pollution emission control usually through an emission charge model. Oh (1995), Malik (1990), and others have modeled the use of enforcement and compliance policy tools in environmental pollution which are similar to other real-world public policy problems such as tax evasion, traffic violation, smuggling, and so on. When regulations are mandated, firms have an incentive to react (or not react) by either facing or evading regulations. Their reaction can then be measured by the level of their environmental performance.

Another way environmental performance is acted upon by firms is through their sensitivity to consumer perception of environmentally-sensitive goods. Hamilton (1995) finds that firms were affected by public reaction to the announcement of the EPA's TRI program. TRI identifies the number of firms responsible for relatively higher levels of chemical releases than their counterparts in the industry. Hamilton discovers that stockholders in firms reporting TRI pollution figures experience "negative, statistically abnormal returns" upon the first release of the information. However, firms may also view regulations as some form of "guiding light" leading them to a more efficient technology path. Palmer et. al admits, for instance, that the EPA Green Lights Program "may have been successful in providing and disseminating new information technologies which may have led to cost-savings or quality-improving innovations" (Palmer et. al, p. 120).

On the last category of environmental performance, firms may also have a precautionary incentive to avoid the cost associated with future regulatory uncertainty. Electric utilities are especially known to diversify the risks associated with fuel costs that are linked to some sort of energy or environmental tax. The risk of future regulation of greenhouse gases is probably a good example to consider. For instance, in the early 90s, the State of Wisconsin has already moved in this direction by rationalizing its new greenhouse-gas environmental adders in their electric utility power plants on the grounds of internalizing future regulatory costs (Hamrin and Reader, 1990). Today, utilities are investing heavily in gas-fired power plants, in part because they are not perceived to carry the same risks as large coal and nuclear plants. Since a utility making production decisions would expect in the event of an energy tax that the expected value of the cost of environmental regulations is not zero, it may diversify its source of electricity supply mix to reduce the exposure of both utilities and their customers to each type of risk. This diversification is therefore reflected on their level of environmental performance.

So far, this chapter rationalizes why firms maintain an environmental performance category. To better understand environmental performance in the context of Repetto's model, a thorough definition is required. Moreover, since production externalities comprise environmental performance, a specific example related to electricity generation is presented below.

Environmental performance and the externality of electricity generation

The environmental performance of firms is defined in this paper as an engineering concept of thermodynamic efficiency. According to a National Academy of Sciences (NAS) study, thermodynamic efficiency is an important measure of industrial processes because it captures the "transformation of materials and energy from crude to usable forms" (Ayres, 1994). This entails that the ratio of waste products to useful salable outputs is one measure of efficiency of the process. Hence, as Repetto puts it, "since all materials that enter an industrial process must come out again in some form as physical outputs, and because matter is neither created nor destroyed," then the ratio of emissions per unit of output produced can be restated as the ratio of "good" outputs to useless "bad" outputs (as opposed the ratio of "bad-to-good" outputs mentioned above)

It is in this context of thermodynamic efficiency that Repetto assumes it makes more sense to hypothesize that industrial processes that transform a greater fraction of energy and materials they use into salable forms might be more profitable. This is why, Repetto particularly tests the Porter hypothesis in the possibility that firms with superior environmental performance also achieve superior profitability among their counterparts. A key component of environmental performance is the production externality associated with electricity generation.

The Acid Rain Program

Acid rain is an environmental damage mainly stemming from coal-burning electric utilities and other industrial processes. It causes acidification of lakes and streams and contributes to the damage of trees at high elevations (EPA, 1996a). In addition, acid rain accelerates the decay of building materials, paints, and cultural artifacts, including irreplaceable buildings, statues, and sculptures. Combined altogether, airborne, SO_2 (sulfur dioxide) and NOx (nitrogen oxide) gases and their particulate matter derivatives, sulfates and nitrates, contribute to visibility degradation and impact public health.

The Acid Rain Program which was established under Title IV of CAAA90 calls for major reductions of SO_2 and NOx, the pollutants that cause acid rain, while establishing a new approach to environmental protection through the use of market incentives. The program sets a permanent cap on the total amount of sulfur dioxide that may be emitted by electric utilities nationwide, about one half of the amount emitted in 1980, and allows flexibility for individual utility units to select their own methods of compliance. The program is being implemented in two phases. Phase I, which began in 1995, will last until 1999, and currently involves 445 generator units. Phase II begins in 2000 and is expected to involve over 2,000 units.

According to EPA, the Acid Rain Program represents a dramatic departure from traditional command and control regulatory methods which establish source-specific emissions limitations. The old command and control regime use technology-based standards set by the state-of-the-art in pollution control at the time the standards are established. Instead, the new program introduces a trading system for SO_2 that facilitates lowest-cost emissions reductions and an overall emissions cap that ensures the maintenance of the environmental goal. The program features tradable SO_2 emissions allowances, where one allowance is a limited authorization to emit one ton of SO_2. Allowances may be bought, sold, or banked by utilities, brokers, or anyone else interested in holding them. Existing utility units were allocated allowances for each future compliance year and all participants of the program are obliged to surrender to EPA the number of allowances that correspond to their annual emissions.

EPA notes that while CAAA90 provides more flexibility to firms, the SO_2 reduction provision in particular remains "controversial" because it represents the first large-scale attempt to set overall emissions levels using marketable licenses (allowances) to control emissions. Since it started in 1995, the SO_2 trading program has not encouraged enough firms to trade, hence the allowance price for SO_2 has been low, according to anecdotal information from the Office of Management and Budget (Theroux, 1996). Allowance permit prices are expected to rise when more utilities are expected to join in SO_2 trading.

III. MODEL DESCRIPTION AND DATA REQUIREMENTS

Augmenting Repetto's test

This chapter lays out the data, identifies the variables, and comments on the statistical test used by Repetto. Before proceeding, however, it is important to identify how Repetto's model was augmented with respect to two variables: profitability and variable cost. For instance, this case study uses the electric utility definition of profits while Repetto uses a two generic definitions of profitability. Moreover, this study augments Repetto's analysis by exploring the association between environmental performance and variable costs as opposed to limiting the analysis to profitability.

Repetto is mainly concerned with the relationship between profitability and environmental performance. To obtain this association, Repetto tests the Porter hypothesis by exploring if firms whose environmental performance is better than their competitors within the industry are more or less successful in the marketplace. Repetto uses profitability as a better proxy for market competitiveness because it tends to "capture all the factors influencing the success of a firm, while sales measure only one aspect of success" (Repetto, p. 11). In doing so, the author then argues that competitiveness is better posed in the form of a profit index rather than sales indices. Moreover, since comparing the stringency of environmental regulations is a difficult task (e.g. legal requirements are difficult to classify), Repetto inquires into actual environmental performance rather than regulatory stringency.

Sample data description

The sample pertains to affected generating units of Phase I utilities. According to the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE), two hundred sixty-one electric power generators that are affected by Phase I are attached to 263 boilers at 261 boiler/generation units at 64 utilities labeled under compliance options (EIA, 1994a). Of the 261 generators, 86 percent are privately owned and the rest are publicly-owned utilities. As previously mentioned, these units were selected by Congress under CAAA90 because they were the highest emitters and the largest units. These units emitted 57 percent of all utility emissions in 1985, and had emissions rates ranging from 2.5 to 10.2 lbs of SO_2/mmBtu of heat input, with an average of 4.2 lbs/mmBtu. Among the sixty-four utilities that comprise the 261 generators affected by Phase I, the sample selected for this study is limited to 50 out of 64 utilities that are reported on EIA's *Financial Statistics of Major U.S. Publicly Owned Utilities* and *Financial Statistics of Major Investor-Owned Electric Utilities* (EIA 1994b; EIA 1994c; and EIA, 1992).

Only 50 of the 64 utilities were used because of data reporting problems. In most cases, the financial information required from these 14 utilities was either available in one period or was absent in the other. While the 50 utilities represents close to eighty percent of the compliance options list under Phase I and may entail some selection bias, this analysis still hopes to portray a rough snap shot of the relationship between environmental performance and profitability, and, more importantly, the cost structure of electric utilities. While the majority of the data includes privately owned utilities, combining both public and private utility data may potentially bias the association between environmental performance and profitability. Since publicly owned utilities are nonprofit operations that have been established to serve their communities at cost (EIA, 1993), 3 publicly owned utilities were dropped from the environmental performance-profitability test known as SCENARIO A. They are: Tennessee Valley Authority (which encompasses Alabama, Kentucky, and Tennessee), City of Kansas City, Missouri, and City of Springfield, Missouri. However, in a second test called SCENARIO B, all 50 utilities were included to explore the association between environmental performance and variable costs.

Description of variables

The variables described below shows the relationship between an engineering concept and two economic concepts, controlling for other extraneous variables. Thermodynamics which is portrayed in this paper as a measure of environmental performance of air pollution is calculated by the ratio of total emissions to total electricity generated. Hence, the variables EPSO2, EPNOX, EPCO2, are environmental performance ratios for sulfur dioxide, nitrogen oxide, and carbon dioxide respectively. In measuring environmental performance, the emissions data were downloaded from EPA's plant-by-plant emissions database (EPA, 1996b). The emissions for each plant were added up to the electric utility or holding company level. To measure economic performance in SCENARIO A, an index of profitability--PROFIT--was used as a better proxy for market competitiveness.

Under economic performance, Repetto's definition of firm profitability is augmented in this paper to better suit the electric utility industry's definition of per kilowatthour of profit. This measure stems from the fact that while there is no perfect measure of firm profits, using DOE's definition of electric utility profits would closely approximate it. In his analysis, Repetto suggests two measures of profitability. First, he defines gross operating margin as the difference between the total value of shipments and total operating costs (including labor, materials, energy, rental, and contract costs), expressed as a fraction of the total value of shipments. The second is the net return as a fraction of the end-of-year book value of fixed capital. This net return is simply the difference between the total value of shipments and total operating costs, less annual depreciation. Repetto admits that neither of these two measures of profitability are perfect. For instance, gross operating margin, which excludes capital costs, would be higher in capital-intensive firms, even if the two were equally profitable. Likewise, the net return on book value reflects a user charge on owned capital, but according to Repetto, such factors as taxes and inflation would accordingly make this measure diverge from the true return on invested capital.

In electric utilities, defining profitability therefore requires knowledge of sales, revenue, and operating income per kilowatthour. Dividing total electricity sales into total revenue which equals revenue per kilowatthour do not equate to profits because some utilities have been able to recoup more revenue per kilowatthour of sale than other utilities. The procedure can also be repeated to derive operating income per kilowatthour (EIA, 1994b). Hence, dividing electricity sales into operating income yields the variable PROFIT, "the residual after meeting production-related operations and maintenance expenses," which, according to EIA, makes this ratio a "rough measure of profitability in electric utilities" (EIA, 1994b, p. 32). Table 1 summarizes the various measures of environmental and economic performance used in this analysis and is compared to Repetto's definition of profitability.

The problem of associating environmental performance and profitability is that it may mask the true impact of regulations on the firm's economic performance when prices vary from one period to the next. For example, since profits is simply the price multiplied by the quantity of output less total cost, a jump in price would increase profits. Hence, in SCENARIO A, the resulting association between environmental performance and profits may be overshadowed by the increase in electricity prices in the second period. To correct for this possible misrepresentation, SCENARIO B was constructed to determine if greater or lesser variable costs are associated with better environmental performance among utilities in the sample. Table 2 summarizes this approach.

According to energy economists at EIA, a close measure of variable costs in electric utilities is operation and maintenance expenses less taxes (EIA, 1996). Hence,

Table 1. Measures of environmental and market performance.

Type of study	Measures of environmental performance	Measures of profitability
This study (by cross-section firm data)	Emissions (ton of SO_2 per dollar of electricity generated by kilowatthour)	Profit: ratio of sales (megawatt-hours) ÷ operating income ($). According to the U.S. Department of Energy, this ratio yields the residual after meeting production related operations and maintenance expenses. Hence, this ma[illegible] treated as a "rough" measu[illegible] of profitability per kilowatt-hour of electricity sold.
Repetto (by product SIC code data)	Toxic release per dollar of shipments; total airborne particulate emissions per dollar of shipments; biological oxygen demand plus total suspended solids per dollar of shipments.	Gross operating margin: (total value of shipments less total operating cots) divided by total value of shipments Net return on book value: (total value of shipments less total operating cots less annual depreciation) divided by book value of invested capital

Table 2. Alternative measure of environmental and market performance

Type of study	Measures of environmental performance	Measures of economic efficiency
This study (by cross-section firm data)	Emissions (ton of SO_2 per dollar of electricity generated by kilowatthour)	Variable costs: ratio of the value of operation and maintenance expenses ÷ kilowatthour of electricity generated. According to the U.S. Department of Energy economists, this ratio yields a "rough" measure of variable costs per kilowatt-hour of electricity generated.
Repetto (by product SIC code data)	Toxic release per dollar of shipments; total airborne particulate emissions per dollar of shipments; and biological oxygen demand plus total suspended solids per dollar of shipments	Variable costs not used in analysis

for coal-fired power plants in electric utilities, the operation component in the variable O&M represents expenses related to utility operations such as power production expenses or steam power operation expenses, supervision and engineering, fuel costs, steam expenses, steam from other sources, electric expenses, miscellaneous steam power expenses, rents, and allowances. While the maintenance component in O&M represents categories such as supervision and engineering costs, structure expenses, boiler plant expenses, electric plant costs, and miscellaneous steam plant expenses. Without the taxes and depreciation, O&M represents approximately 85 percent of total utility operating expenses, which is a close approximate of variable costs.

A comment on correlations testing

The problem with correlations is that the association between two variables does not in any way mean causation. In statistics, the correlation coefficient is often subject to misinterpretation (Huntsberger and Billingley, 1973). One of the main reasons stems from the frequently false assumption that because two variables are related, a change in one causes a change in the other. For instance, two variables may appear to be highly correlated when, in fact, they are not directly associated with each other but are both highly correlated with a third variable. Because of sampling variation, it is possible to obtain a significant correlation when the variables are not related. However, as long as the researcher is aware of this possibility, the probability of this kind of error can be controlled by selecting the level of significance. Hence, it is the unwarranted cause-and-effect assumption and the spurious correlation that researchers and the like must be aware of.

Since other factors conceal the true effects of environmental costs on profits, simple correlations do not reveal much other than simple association between environmental performance and profits. According to Repetto, older plants, for example, are probably both dirtier and have higher production costs, because they embody outmoded process technologies. This may be so because they are hard to retrofit with efficient pollution control equipment, and because they may require a lot of maintenance to prevent leaks and emissions. Moreover, larger plants also probably achieve economies of scale, both in producing their primary outputs and in treating or controlling emissions. These differences which may affect both profitability and pollution-intensity among plants in an industry, could create spurious correlations between economic and environmental performance or overshadow whatever true associations may exist.

To guard against this possibility of spurious correlation, this paper analyses the association between environmental performance and profitability using partial correlation methods in addition to simple correlations. Most statistical textbooks say that partial correlation analysis is a technique for exploring the association between two variables while removing the influence of extraneous variables that influence both (Greene, 1994). Hence, it is a way of controlling statistically for the effects of extraneous variables or by holding them constant. Partial correlation coefficients was calculated for the samples in each scenario, controlling for the following variables: (1) INVADJ, the amount of recent investments in plant and equipment as a fraction of book value of capital; (2), SCALE, the scale of production measured by the total electric nameplate capacity, and (3) AGE, the average age of the plants of each utility.

What can be said about these control variables? In electric utilities, INVADJ can be measured by the sum of total general plant and equipment investments such as structures and improvements, office equipment, transportation equipment, stores equipment, tools, shop, and garage equipment, laboratory equipment, power operated equipment, communication equipment, and other miscellaneous equipment. INVADJ is normalized by the end-of-year book value of fixed capital. SCALE is measured in electric utilities by the amount of electric power delivered or required for which a generator, turbine, transformer, transmission circuit, station, or system is rated by the manufacturer. Generator nameplate capacity is usually indicated on a nameplate attached physically to the equipment. Finally, AGE is the average age of generator nameplate capacity of each utility's power plant since it's initial year of operation to the year the data was reported.

To summarize, Chapter III discusses in detail the type of variables used in Repetto's model. The test was augmented in two ways to distinguish the impact of regulations on profitability (SCENARIO A) and on variable costs (SCENARIO B). This chapter cautions the use of correlations testing in that the association between two variables do not necessarily mean causation.

IV. SETTING UP THE STATISTICAL TEST

Standard versus Porter hypothesis sign expectations

This chapter defines what the correlation signs mean and what to expect under each scenario; it also sets up Repetto's statistical test. According to Repetto, the standard hypothesis would show that better environmental performance comes at a cost. Hence, he stresses that "firms that divert resources to reduce their emissions beyond the point where waste recovery just pays for itself must sacrifice some profits" (Repetto, p. 14). Under this hypothesis, environmental performance and profitability should be inversely related in SCENARIO A. The competing Porter hypothesis, however, claims that once firms are motivated to seek out solutions to environmental problems (e.g. by regulatory action), they "typically find previously overlooked cost-saving opportunities to improve processes, reduce wastes, or redesign products" (Repetto, p. 11) Correlations between environmental performance and profitability under SCENARIO A would therefore be positive under the standard hypothesis, while it is negative under the Porter hypothesis.

Since environmental performance is paired with variable cost in SCENARIO B, a negative correlation validates the standard hypothesis while a positive correlation corresponds to the Porter hypothesis. This stems from the assumption that higher costs go in the opposite direction of lower environmental performance (ratio of bad-to-good output increases). Conversely, when higher costs are also associated with better environmental performance ratios (e.g. ratio of bad-to-good output decreases), this result tends to validate the standard hypothesis. Table 3 summarizes these sign expectations.

The statistical test

The test for environmental performance and profitability under SCENARIO A can then be stated as follows: reject the null hypothesis, Ho, that environmental regulations are associated with profitability if the simple correlation is positive. Conversely, accept the alternative hypothesis, Ha, that environmental regulations are divorced from profitability if the simple correlation is negative.

SCENARIO A (simple correlations)

(1) reject Ho if $\rho_{sc} > 0$, where:

ρ_{sc} = simple correlation between environmental performance and profitability; and

Ho = implies that regulations are associated with profits;

Table 3. Expectations and interpretations of correlation signs between environmental performance-profitability tradeoff and performance-variable cost tradeoff.

Type of hypothesis	**Environmental performance** (ratio of bad-to-good outputs: e.g. ton of SO_2, NOx, and CO_2 per kilowatthour of electricity generated) and **profitability** (ratio of sales-to-operating income: e.g. dollar-per-kilowatthour)	**Environmental performance** (ratio of bad-to-good outputs: e.g. ton of SO_2, NOX, and CO_2 per kilowatthour of electricity generated) and **variable cost** (ratio of operation and maintenance expenses less taxes and depreciation: e.g. per dollar-per-kilowatthour)
Repetto's study		
Standard hypothesis	positive	not applicable
Porter hypothesis	negative	not applicable
This study	SCENARIO A	SCENARIO B
Standard hypothesis	not applicable	negative
Porter hypothesis	not applicable	positive

(2) accept Ha if $\rho_{sc} < 0$, where:

Ha = regulations are divorced from profits.

Converting the simple correlation test to a partial correlations test controlling for INVADJ, SCALE, and AGE, the test is stated as:

SCENARIO A (partial correlations)

(1) reject Ho if mean bootstrapped value = 0; where:

ρ_{pc} is partial correlation which *nets* out the effects of extraneous variables; and

Ho = regulations are significantly associated with profits before and after CAAA90;

(2) accept Ha if mean bootstrapped value < or > 0, where:

Ha = regulations are significantly divorced from profits before and after CAAA90.

Likewise, The test for environmental performance and variable cost under SCENARIO B is stated as follows: reject the null hypothesis, Ho, that environmental regulations are associated with cost if the mean bootstrapped value is equal to zero. Conversely, accept the alternative hypothesis, Ha, that environmental regulations are divorced from cost if the mean bootstrapped value is not equal to zero.

SCENARIO B (simple correlations)

(1) reject Ho if $\rho_{sc} < 0$, where:

ρ_{sc} = simple correlation between environmental performance and variable cost;

and Ho = implies that regulations are associated with efficiency;

(2) accept Ha if $\rho_{sc} > 0$, where:

Ha = regulations are divorced from costs.

Converting the simple correlation test to a partial correlations test controlling for INVADJ, SCALE, and AGE, the test is stated as:

SCENARIO B (partial correlations)

(1) reject Ho if mean bootstrapped value = 0; where:

ρ_{pc} is partial correlation which *nets* out the effects of extraneous variables; and

Ho = regulations are significantly associated with profits before and after CAAA90;

(2) accept Ha if mean bootstrapped value < or > 0, where:

Ha = regulations are significantly divorced from profits before and after CAAA90.

There are two ways of calculating the simple and partial correlations. They are outlined as follows:

First method

1.) The correlation between EPSO2 and PROFIT is the simple correlation between EPSO2 and PROFIT.

2.) The partial correlation between EPSO2 and PROFIT controlling for Z (Z = INVADJ, SCALE, and AGE) is:

OLS EPSO2 on Z, and save residual as RESID1

OLS PROFIT on Z, and save residual as RESID2.

Therefore, the partial correlation between EPSO2 and PROFIT controlling for Z is just the simple correlation between RESID1 and RESID2.

Greene (1994) also shows a simpler way in obtaining the partial correlation coefficient as a function of t-values.

Second method

1.) OLS EPSO2 on PROFIT, Z.

2.) Use t-value of PROFIT in regression in the equation $r_{EPSO2,\,PROFIT}$ below.

3.) The partial correlation between EPSO2 and PROFIT is therefore:

$r_{EPSO2,\,PROFIT} = t^2_{PROFIT} / (t^2_{PROFIT} + \text{degrees of freedom}) \approx$ simple correlation between RESID1 and RESID2.

Either of these two methods will generate the same simple and partial correlation coefficients. To minimize the amount of time it takes to run individual regressions and calculate the different correlations, the simulations were customized in a SAS code.

V. RESULTS

This chapter examines the simple and partial correlation results under SCENARIO A and SCENARIO B. Recall that correlations under SCENARIO A would be positive under the standard hypothesis, while it would be negative under the competing Porter hypothesis. However, correlations under SCENARIO B would be negative under the standard hypothesis and positive under the Porter hypothesis. The results in both scenarios show that since the signs of the simple and partial correlation coefficients match the sign expectations stated in Table 3, this tends to validate the Porter hypothesis. However, these correlation coefficients are only valid if they pass two significance tests.

In Tables 4-5, the simple and partial correlations portray that the environmental performance of SO_2, NOX, and CO_2 are either negatively associated with profitability or are positively associated with variable costs. Statistically, these results lead to rejecting Ho and accepting Ha under SCENARIO A that environmental regulations are divorced from profits. Likewise, the results under SCENARIO B lead to rejecting Ho and accepting Ha that regulations are divorced from variable cost. From these results, the reader may be tempted to generalize that there is no tendency for superior profitability of

Table 4. SCENARIO A: Profitability and SO_2, NOx, and CO_2 environmental performance of Phase I compliance utilities, before and after CAAA90 (1990 - 1994).

Type of correlation	Correlations[1] Before CAAA 1990	Correlations[1] After CAAA 1990	Significance[2] Percent change	Significance[2] Significant at 5% level?
Simple correlation:				
EPSO2 and PROFIT	-0.268	-0.315	+29.501	No
EPNOX and PROFIT	-0.214	-0.156	-40.969	Yes
EPCO2 and PROFIT	-0.183	-0.173	+24.324	No
Partial correlation: (controlling for: investments in plant & equipment ÷ book value; age of plant; and scale of plant)				
EPSO2 and PROFIT	-0.261	-0.338	+29.501	No
EPNOX and PROFIT	-0.227	-0.134	-40.969	No
EPCO2 and PROFIT	-0.185	-0.140	+24.324	No

[1] Simple correlation between EPSO2 and PROFIT, EPNOX and PROFIT, and EPCO2 and PROFIT.

[2] See Appendix B for simple correlations significance method and Appendix C for partial correlations significance method. Results of significance test presented in Tables 6 and 7 for simple correlations, and Tables 8 and 9 for partial correlations.

Table 5. SCENARIO B: Variable cost and SO_2, NOx, and CO_2 environmental performance of Phase I compliance utilities, before and after CAAA90 (1990 - 1994).

Type of correlation	Correlations[1] Before CAAA 1990	After CAAA 1990	Significance[2] Percent change	Significant at 5% level?
Simple correlation:				
EPSO2 and O&M	+0.571	+0.059	-99.989	Yes
EPNOX and O&M	+0.524	+0.486	-07.251	Yes
EPCO2 and O&M	+0.627	+0.366	-41.626	Yes
Partial correlation: (controlling for: investments in plant & equipment ÷ book value; age of plant; and scale of plant)				
EPSO2 and O&M	+0.569	+0.048	-91.564	No
EPNOX and O&M	+0.548	+0.503	-08.212	No
EPCO2 and O&M	+0.628	+0.384	-38.850	No

[1] Simple correlation between EPSO2 and PROFIT, EPNOX and PROFIT, and EPCO2 and PROFIT.

[2] See Appendix B for simple correlations significance method and Appendix C for partial correlations significance method. Results of significance test presented in Tables 6 and 7 for simple correlations, and Tables 8 and 9 for partial correlations.

electric utilities in the sample to be correlated with greater emissions before and after CAAA90. Even when controlling for extraneous variables, the results show that there is no tendency for higher SO_2, NOX, and CO_2 to be associated with higher profitability. However, could the correlation coefficients have arisen by chance if the true correlation between environmental and economic performance is zero?

Two types of significance tests were calculated to determine if the correlation before CAAA90 and after CAAA90 are distinctly different from each other. They are summarized in Tables 4-5 (last column on the right), but are displayed in greater detail in Tables 6-7 and Tables 8-9. Particularly, the significance test results for simple correlations under SCENARIO A and SCENARIO B are shown in Table 6 and Table 8 respectively while those of partial correlations are displayed in Table 7 and Table 9.

With the exception of NOx under SCENARIO A, the significance tests shown in Table 4 portrays that while the association between environmental performance of SO_2 and CO_2 and profitability tends to validate the Porter hypothesis, their association is not valid at the 5-percent level of rejection under the two periods. Although CO_2 does not directly contribute to acid rain, it does contribute to the what known as the greenhouse

Table 6. SCENARIO A significance test on the change in simple correlation of profitability and environmental performance before and after CAAA90.[1]

Sulfur dioxide	Nitrogen oxide	Carbon dioxide
Z1 = 0.137304	Z1 = 1.221465	Z1 = 0.883301
Z2 = 1.496575	Z2 = 1.340627	Z2 = 0.103514
sigma = 0.208514	Sigma = 0.208514	sigma = 0.2236078
Z = 6.518830	Z = -0.571480	Z = 3.4873103
α = 0.05 = 1.96	α = 0.05 = 1.96	α = 0.05 = 1.96
Conclusion: Reject Ho.	Conclusion: Do not reject Ho.	Conclusion: Reject Ho.

[1]Z-test computation for two correlation coefficients:
Let Z be the change in the competitiveness-performance correlation before and after CAAA90. Ho: Z is significant. Ha: Reject Ho.

Table 7. SCENARIO B significance test on the change in simple correlation of variable cost and environmental performance before and after CAAA90.[1]

Sulfur oxide	Nitrogen oxide	Carbon dioxide
Z1 = -0.74991424	Z1 = -0.3619228	Z1 = -0.4012797
Z2 = -0.63335794	Z2 = -0.5001581	Z2 = -0.4263356
sigma = 0.215665546	sigma = 0.2156655	sigma = 0.2156655
Z = 0.540449384	Z = 0.6409709	Z = 0.1161796
α = 0.05 = 1.96	α = 0.05 = 1.96	α = 0.05 = 1.96
Conclusion: Do not reject the Ho.	Conclusion: Do not reject the Ho.	Conclusion: Do not reject the Ho.

[1]Z-test computation for two correlation coefficients:
Let Z be the change in the competitiveness-performance correlation before and after CAAA90. Ho: Z is significant. Ha: Z is insignificant.

Table 8. SCENARIO A significance test on the change in partial correlation of profitability and environmental performance before and after CAAA90.

Category	SO_2 performance and market competitiveness	NOx performance and market competitiveness	CO_2 performance and market competitiveness
Partial correlation **before** CAAA90	-0.26091	-0.22704	-0.18531
Partial correlation **after** CAAA90	-0.33849	-0.13444	-0.14022
Difference	0.07758	-0.09259	-0.04509
Number of bootstrap samples	2000	2000	2000
Mean bootstrapped value	**0.08044**	**-0.06649**	**-0.05186**
Median bootstrapped value	0.08149	-0.07421	-0.04002
95% bootstrap percentile confidence interval: lower endpoint	-0.15256	-0.33582	-0.40599
95% bootstrap percentile confidence interval: upper endpoint	0.33258	0.24414	0.26016
Are the change in partial correlations before and after CAAA90 significant?	No	No	No

Table 9. SCENARIO B significance test on the change in partial correlation of variable cost and environmental performance before and after CAAA90.

Category	SO_2 performance and variable cost	NOx performance and variable cost	CO_2 performance and variable cost
Partial correlation **before** CAAA90	0.56942	0.54761	0.62881
Partial correlation **after** CAAA90	0.04799	0.50339	0.38393
Difference	0.52143	0.044218	0.24488
Number of bootstrap samples	2000	2000	2000
Mean bootstrapped value	**0.43279**	**0.09232**	**0.20753**
Median bootstrapped value	0.50811	-0.06022	0.22667
95% bootstrap percentile confidence interval: lower endpoint	-0.57026	-0.82808	-0.94587
95% bootstrap percentile confidence interval: upper endpoint	1.02728	0.97818	1.15143
Are the change in partial correlations before and after CAAA90 significant?	No	No	No

effect or global warming. CO_2 was included in this analysis as a way to check the relative behavior of the other two chemical releases which both contribute to acid rain. Surprisingly, SO_2 fares in the same insignificance category as CO_2 under SCENARIO A. While the simple correlations results under SCENARIO A are mostly insignificant, the same correlations under SCENARIO B turns out to be significant (Table 5 and Table 7). The problem with this result is that simple correlations test are subject to spurious correlation problems. Hence, while the statistical test leads to the acceptance of the null hypothesis that environmental regulations are associated with lesser variable cost, the reader would still find it difficult to make this conclusion because of the spurious correlations argument.

Even when controlling for the effects of extraneous variables, environmental performance is not significantly associated with profitability under SCENARIO A. It is also not significantly associated with variable cost under SCENARIO B. The Fischer Z test (Kanji, 1993) is a convenient method to explore the difference between two simple correlations because the distribution of the variance (square of sigmas in Table 6) does not stem from a stochastic distribution (Hallahan, 1995). However, in the case of partial correlations, the distribution of the variance is uncertain because it now becomes a function of the residuals of the control variables INVADJ, SCALE, and AGE. To test the difference between two partial correlations, therefore, a distribution of the variance must be estimated first. Hallahan's bootstrap regression algorithm was employed to generate a distribution of the variance upon which confidence intervals can be constructed similar to the way Monte Carlo simulations are modeled (see bootstrap methods in Appendix C).

The partial correlations significance test results generated by bootstrap simulations in Tables 8-9 show that even when controlling for the effects of extraneous variables such as INVADJ, SCALE, and AGE, the association between environmental performance and profitability under SCENARIO A and those of performance and variable cost under SCENARIO B is insignificant. Before reaching this conclusion, 2000 bootstrap samples were arbitrarily assigned since the greater the sample, the more accurate the confidence interval is. The significance test in under SCENARIO A is therefore stated as follows: reject the null hypothesis that the partial correlations between environmental performance and profitability in the two periods (before and after CAAA90) are significant if the mean bootstrap value with a 95-percent confidence interval does not go through zero. The same null hypothesis is repeated under SCENARIO B with environmental performance and variable cost as the variables in question. Since the mean bootstrap values under SCENARIO A and SCENARIO B goes through zero, this leads to the rejection of Ho in both scenarios.

Some explanations of environmental improvement

Because the correlation signs portray what one may expect to occur under the Porter hypothesis, this section explains what lead to the improvement of environmental and economic performance since CAAA90. EPA notes that the utilities specified in both samples decreased their emissions from either switching to lower sulfur coal and consequently from reduction in their generating units's utilization. Since 1980, emissions from these heavy emitters (Phase I units) have declined in every one of the 21 states by a total of roughly 5.6 million tons (EPA, 1996b). Accordingly, over 43 per cent of the reduction was achieved by the utilities in just three states: Ohio, Indiana, and Missouri. These states contained close to a third of the units participating in Phase I and represented some of the highest emitting plants. Other regulatory compliance options such as pollution control technologies (e.g. scrubbers) that were used by utilities also lead to this environmental improvement (EIA, 1994a).

Why was environmental performance associated with the enhancement in profitability and cost reduction? Supporters of the Porter hypothesis would probably say that environmental regulations may have likely caused this phenomena in electric utilities. For instance, for his part, Repetto thinks that "since environmental performance makes firms no less profitable, institutional and fiduciary investors should not expect to earn lower portfolio returns if they invest in the stocks of firms with superior environmental performance within the industry" (Repetto, p. 15). A careful look at the data, however, shows that the empirical results of this paper tend to validate the Porter hypothesis because of several outliers in the sample. Figure 3 shows that while a majority of electric utilities slightly increased their cost structure by an average 0.09 percent four years after the Acid Rain Program was announced, this increase is overwhelmed by those utilities in the sample who have greatly decreased their cost. As a consequence, the overall average decline in variable cost of 1 percent in some utilities offsets the increase of 0.09 percent in other utilities. The correlations therefore tend to show that as average environmental performance improves, (e.g. due to low sulfur switching), average variable cost tends to decline. Hence, since better environmental performance moves jointly with a better cost structure, the correlations tend to validate the Porter hypothesis.

VI. CONCLUSIONS AND RECOMMENDATIONS

The Porter hypothesis presents an interesting paradigm that through regulatory action, firms can be motivated to pursue technological innovation. This paper tests the Porter hypothesis by using an augmented version of Repetto's model. The empirical results show that while the sign of the coefficients tend to validate those of the Porter hypothesis, the association between environmental and economic performance is either subject to a spurious correlation problem when they are significant or is simply insignificant when the effects of extraneous variables are netted out. Although greater emissions were abated after CAAA90, the reader should be aware that correlations do not mean causation. Emissions were abated due to low-sulfur coal switching and by other

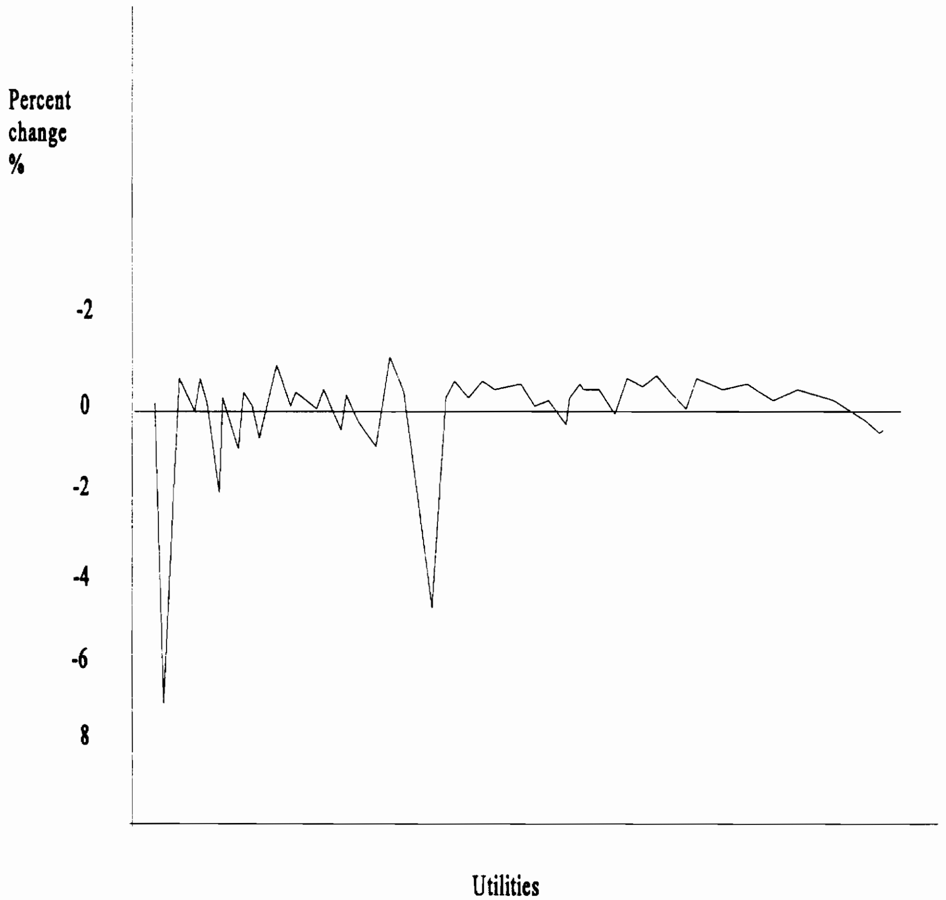

Figure 3: Evolution of variable cost (before and after CAAA90).

compliance options set by the Acid Rain Program. A utility's ability to increase its abatement expenditures however does not mean it is efficient.

A few recommendations are suggested. First, since SO_2 trading started over a year ago and may gain momentum in the near future, this activity ought to be modeled in this type of analysis. Secondly, the effects of extraneous variables should be expanded to more than three variables. Some suggested control variables include air and water abatement expenditures and the cost of demand-side management programs. Finally, while correlation tests are sometimes useful, they can be misleading. Hence, perhaps a better way to test the Porter hypothesis is to use an authentic cost-benefit analysis model such as those of Jaffe et al. (1994) and Jaffe and Stavins (1994).

APPENDIX A: Comparative Statics

Profit function approach

To illustrate how environmental regulations affect firm market competitiveness, Figure 4 portrays a hypothetical firm which maximizes profits subject to two inputs: (1) x1, the avoidance activity, and (2) x2, the R&D activity; both costs w1 and w2 respectively to produce output Y which sells at market price P.

Hence, we need the following variables:

x1 = avoidance activity, an input worth consuming

x2 = R&D activity, an input worth consuming

w1 = price of avoidance

w2 = premium of R&D activity

P = output price

Y = quantity of output

to obtain the profit function:

(1) $\text{Max} \prod f(x1, x2) = P*Y - w1x1 - w2x2,$

where x1 and x2 are factor inputs to production (e.g. electricity generation) and:

x1 = The avoidance activity; the firm maximizes profits by avoiding regulations and applying "band-aid" solutions and other methods in avoiding pollution reduction (also see

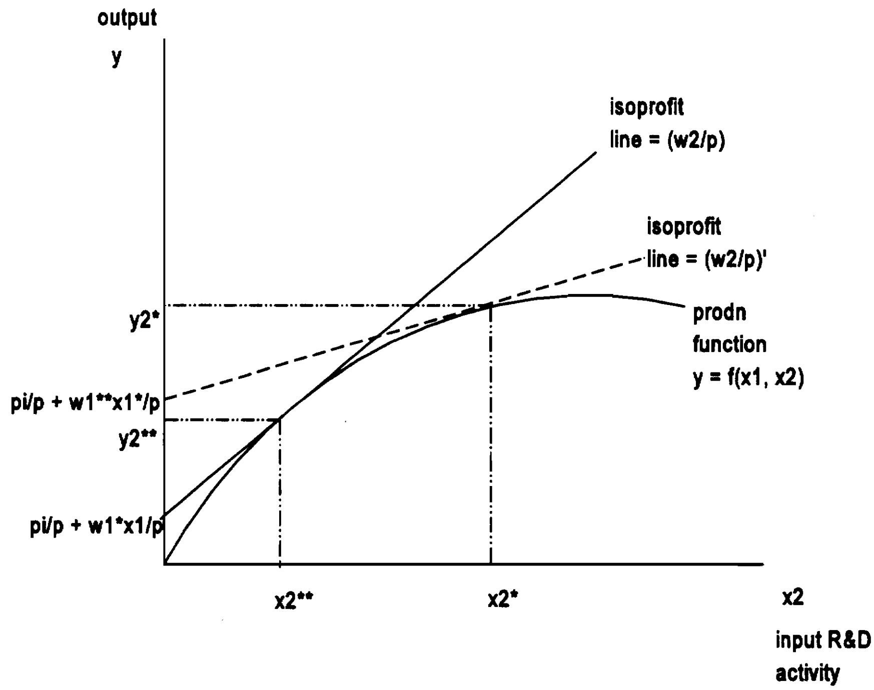

Figure 4: Profit-maximzing firm with no input restrictions

Oh, 1995; Hamilton, 1995; and Malik, 1990).

x2 = The R&D activity. Represents as an insurance activity where the firm takes steps towards fully incorporating environmental regulations into resource decisions (Union of Concerned Scientists, 1993). Firms may attempt to quantify these risks before investing in new power plants, rather than assuming, as most do now, that no new regulatory costs will be incurred.

The first order conditions are set up to obtain the optimal inputs $x1^*$ and $x2^*$. Then if the output price is multiplied to marginal product of factor 1, it should equal to the factor price. Thus, the output price P times marginal product of factors 1 and 2 at the optimum is equal to the price of the input (w1 and w2):

(2) $P*MP1 (x1^*, x2) = w1$ and

(3) $P*MP2 (x1^*, x2) = w2$.

Regulations could then affect both input prices directly and output prices indirectly:

Direct effect

Input prices could be positively or negatively affected by the probability of avoidance activities and the risk of getting caught (x1):

(3) Tax = f[Pr_{w1} (avoidance, risk)]. Hence, if $Pr_{w1}>0$, the higher the "tax" on the polluting input; if $Pr_{w1}<0$; the lower the "tax" on the polluting input.

Regulatory action may also influence the probability of less activity avoidance, and scale of R&D:

(4) Subsidy = f[Pr_{w2} (less avoidance, scale)]. Hence, if $Pr_{w2}>0$, the higher the "subsidy" on the polluting input; if $Pr_{w2}<0$; the lower the "subsidy"on the polluting input.

Indirect effect

The probability of output prices could go up or down depending on consumer reaction to the firm's environmental performance:

(5) P = f[Pr_P (x1>0)], the probability that prices will drop depends on the consumption of the polluting input, x1; and

(6) P = f[Pr_P (x2>0)], the probability that prices will increase depends on the consumption of R&D activity, x2.

How could regulations affect firm profitability?

Recall that $P^*MP_i(x1^*, x2^*) = w_i$, the value of the marginal product of the ith optimal factor is equal to its cost, the input price.

Hence if the value of the marginal product is greater than (less than) its cost, $w_i \Delta x_i$, when the ith input price decreases (increases), profits can then be increased (decreased) by increasing (decreasing) the quantity of the ith input.

The direct effect can be summarized as

(7) $P^*MP_i(x1^*, x2^*) > (w_i\downarrow)\Delta x_i \Rightarrow x_i \uparrow \text{ to } \uparrow \prod;$

(8) $P^*MP_i(x1^*, x2^*) < (w_i\uparrow)\Delta x_i \Rightarrow x_i \downarrow \text{ to } \uparrow \prod.$

Similarly, if the value of the marginal product is greater than (less than) its cost, $w_i \Delta x_i$, when the output price increase (decrease), then profits can be decreased (increased) by decreasing (increasing) the quantity of the ith input.

The indirect effect can be summarized as

(9) $(P\uparrow)^*MP_i(x1^*, x2^*) > w_i\Delta x_i \Rightarrow x_i \uparrow \text{ to } \uparrow \prod;$

(10) $(P\downarrow)^*MP_i(x1^*, x2^*) < w_i\Delta x_i \Rightarrow x_i \downarrow \text{ to } \uparrow \prod.$

Note that the firm should also be able to substitute away one input for another in the case of a tax on the polluting input, or a subsidy for another more expensive input (Figure 4). Profit-minimization can be still be attained at x2*.

To summarize, regulations directly (input prices) and indirectly (output prices) affect a firm's profitability. If it is worth to the firm to consume the input, profitability therefore depends on whether or not a firm substitutes its consumption for other inputs as relative prices change. Hence, if the input is not worth consuming to the firm, the impact on firm profitability is ambiguous.

APPENDIX B: Fischer Z-test of two correlations

The following test is illustrated by Kanji (1993). Let the significance of the difference between the correlation coefficients for a pair of variables occurring from two different populations and let the difference be ρ_1 and ρ_2 where the assumptions are: (1) x and y values originate from normal distributions, (2) the variance in the y values is independent of the x values, and (3) the relationships are linear.

The test statistic is then,

Ho: Z is significant

Ha: Reject Ho if otherwise.

$Z = [(Z_1 - Z_2) - (\mu_{Z1} - \mu_{Z2})] / [\sigma]$,

where:

$\sigma = (\sigma^2_{Z1} + \sigma^2_{Z2})^{1/2}$,

$Z_i = ½\log_e(1 + r_1)/(1 - r_1) = .1513\log_{10}(1 + r_1)/(1 - r_1)$, forms the *i*th population,

r_1 = the simple correlation coefficient before CAAA90,

r_2 = the simple correlation coefficient after CAAA90,

mean $\mu_{Z1} = ½\log_e[(1 + \rho_1)/(1 - \rho_1)]$,

variance $\sigma_{Z1} = 1/(n_1 - 3)^{1/2}$,

n_1 is the size of the first sample,

and Z now follows a normal distribution with mean zero and with variance 1.

Example data under SO_2:

$n_1 = 44$, $n_2 = 44$, $r_1 = -0.267$, $r_2 = -0.328$, $\alpha = 0.05$

$Z_1 = .1513\log_{10}(1 + r_1)/(1 - r_1) = -0.137304$

$Z_2 = .1513\log_{10}(1 + r_1)/(1 - r_1) = 1.496575$

$\sigma = [\{1/(n_1 - 3)\} + \{1/(n_2 - 3)\}]^{1/2} = 0.2085$

$Z = (-0.137304 - -0.78314206)/(0.2085) = -6.5192854$

with a critical value $\alpha = 0.05$ is 1.96, and since Z value falls under

rejection region, reject Ho.

APPENDIX C: Bootstrap methods

The following bootstrap methodology is adapted from Hallahan (1995) and is applied to this analysis. Other key references also include the following:

Jeong, J. and G. Maddala. "A Perspective on Application of Bootstrap Methods in Econometrics" in *Handbook of Statistics* Vol. 11, Chapter 21.

•Leger, C., Politis, D. and J. Romano. "Bootstrap Technology and Applications." *Technometrics* (1992), 378-398.

•Vinod, H.D. "Bootstrap Methods: Applications in Econometrics" in *Handbook of Statistics* Vol. 11, Chapter 23.

Let P = an unknown stochastic model and

χ = be the data shown from P.

Single sample case:

$X \sim F$ with mean μ and variance σ^2.

$P \equiv F$

$X = (X_1, \ldots, X_n)$ random sample from F.

Two-sample case:

$Y \sim F$ with median m_y

$Z \sim$ G with median m_z

$X = (y_1, \ldots, y_m, z_1, \ldots, z_n)$

$y_1, \ldots, y_m$ random sample from F

$z_1, \ldots, z_n$ random sample from G

$P = (F, G)$.

Regression model case:

$y = X\beta + \epsilon$

$\epsilon \sim$ F with mean 0 and variance σ^2

$P = (F, \beta)$

From the three examples above, we assume $R(\chi, P)$ is some quantity of interest such that

$$\theta = \theta(P) = a\ parameter\ of\ P$$

$$\hat{\theta} = S(X) = an\ estimator\ of\ \theta$$

and therefore,

$$R(\chi, P) = \hat{\theta} - \theta(P)$$

(where the parameter = function of F, distribution function and the statistic or estimator = function of X, sample). For example,

$$\mu = E_i\ (X)\ where\ \bar{X} = S(X) = 1/n\ (\textstyle\sum_i,\ i = 1...n)\ X_i.$$

From above, the following questions are drawn:

What is the standard error of $\hat{\theta}$?

Is it biased?

Find the confidence region for θ(P).

$$\theta = \mu,\ \hat{\theta} = \bar{X},\ se_F(\bar{X}) = \frac{\sigma}{\sqrt{n}},\ so,\ \hat{se}_F(\bar{X}) = \frac{\hat{\sigma}}{\sqrt{n}}$$

In some cases, there are closed-form answers. For example, in the single case example stated above, with where

$$\hat{\sigma}^2 = \frac{1}{n-1}(\textstyle\sum_i,\ i = 1...n)\ (X_i - \bar{X})^2.$$

But in the two-sample case, with $\theta = m_y - m_z$, there are no formulas for the standard error of the difference of two medians!

Therefore, it needs sampling distribution of $R(\chi, P)$ under P, say J(P) such that given the data X, we let $\hat{P}$

be an estimate of P and we let X^* be generated from $\hat{P}$

and we let

$$J(\hat{P}) \text{ be the sampling distribution of } R(X^*, \hat{P})$$

$$\text{where } J(\hat{P}) \text{ is the boostrap approximation towards } J(P).$$

Hence, we need to map the real world into the bootstrap world:

REAL WORLD
Unknown prob. model $P \rightarrow\rightarrow$ *observed data* $X = (X_1,...,X_n) \rightarrow\rightarrow \hat{\theta} = S(X)$, *the statistic of interes*

⇓⇓⇓

⇓⇓⇓

BOOTSTRAP WORLD

Est. prob. model $\hat{P}_x \to\to$ *bootstrap sample* $X^* = (X_1^*, \ldots, X_n^*) \to\to \hat{\theta}^* = S(X^*)$, *bootstrap replication.*

Thus, we relate real world $R(\chi, P) \sim J(P)$, [J(P) is unknown] to bootstrap world

$R(X^*, \hat{P}) \sim J(\hat{P})$, *since, given X, we know* $\hat{P}$, *use Monte Carlo towards* $\approx J(\hat{P})$.

Usually, the explicit form for

$$J(\hat{P})$$

is not available (e.g. differencing sample medians). Hence, there's a need to simulate

$$J(\hat{P})$$

by the following Monte Carlo resampling algorithm:

Bootstrap algorithm

Given data X , $\hat{P}$ *based on X, generate B iid samples* $X_1^*, \ldots, X_B^*$ *of* $\hat{P}$).

Then, calculate B values $R[X_1^*,\theta(\hat{P})],\ldots,R[X_B^*,\theta(\hat{P})]$.

The empirical distn of $R[X_i^*,\theta(P)]$, $i=1\ldots B$ *is* ≈ *towards bootstrap distn* $J(P)$.

Example: Test significance evolution of SO_2 partial correlations over time.

y ~ F and z ~ G, let P = (F,G)

where:

y = residuals from regressing EPSO2, EPNOX, and EPCO2 on PROFIT, controlling for INVADJ, SCALE, and AGE before CAAA90, and

z = residuals from regressing EPSO2, EPNOX, EPCO2 on PROFIT, controlling for INVADJ, SCALE, and AGE after CAAA90.

θ = median (y) - median (z).

Given observed data: $y = (y_1,\ldots,y_m)$ from F

$Z = (z_1,\ldots,z_n)$ from G

leads to

$\ddot{P} = (\ddot{F},\ddot{G})$ *where* $\ddot{F}$ *edf of data* y; $\ddot{G}$ *edf of data* z (*edf = empirical distn fcn*).

$$G = \textit{discrete distn on } (z_1,\ldots,z_n) \textit{ with weight } \frac{1}{n} \textit{ on each } z_i.$$

$$\hat{F} = \textit{discrete distn on } (y_1,\ldots,y_m) \textit{ with weight } \frac{1}{m} \textit{ on each } y_i.$$

where X = (y, z) and

$$\theta = S(X) = median\ (y_1,\ldots,y_m) - median\ (z_1,\ldots,z_n).$$

Need to map R(χ, P) =

$$\hat{\theta}$$

and J(P) = distribution of R(χ, P) which is unknown, to

$$\hat{P} = (\hat{F}_{\hat{m}},\hat{G}_n),\ a\ bootstrap\ sample\ X_i^* = (y_i^*,z_i^*),$$

where y_i^* = random sample (with replacement) of size m from y

z_i^* = random sample (with replacement) of size n from z

and obtain bootstrap replication of

$$\hat{\theta}_i^* = R[X_i^*,\theta(\hat{P})] = median\ (y_i^*) - median\ (z_i^*)\ , where\ i = 1,\ldots B.$$

So, empirically generate B values such that

$$\hat{\theta}_1^* = median\ (y_1^*) - median\ (z_1^*)\ ,$$

$$\hat{\theta}_2^* = median\ (y_2^*) - median\ (z_2^*)\ ,$$

$$\vdots$$

$$\hat{\theta}_B^* = median\ (y_B^*) - median\ (z_B^*)\ ,$$

and use these to approximate

$$J(\hat{P})\ which\ approximates\ J(P).$$

To find an upper and lower 95% confidence bound for θ(F, G), set sampling distribution of B = 2000 to obtain 2000 bootstrap samples drawn for before and after CAAA90 data sets. Then, calculate the difference of partial correlations for the two time periods and obtain compare the upper and lower bound values with the mean bootstrapped value. Because the mean bootstrapped value goes through the origin, conclude that there is no significant difference.

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Vita

Anton Raneses received his B.A. degree in economics from the University of California at Davis in 1992 and started the M.A. in economics program at Virginia Tech in 1993. The author has an extensive experience in economic policy analysis ranging from U.S. foreign agricultural trade policy, climate change impacts on agriculture, biological diversity, biotechnology, industrial uses of agricultural materials, and renewable energy issues. The author is now employed as a research analyst at the Antitrust Division, U.S. Department of Justice. Because of his interest in environmental issues, the author will pursue a second master's degree in environmental science and engineering at the Johns Hopkins University in 1997.