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Abstract

A controversy exists among economists who have found, based on aggregate data analysis, that environmental regulations tend to retard productivity, and business strategists who maintain, based on case analysis, that environmental regulations can enhance productivity. A key point often overlooked in this controversy is that all parties agree that environmental regulations are more likely to enhance productivity if they are well designed. Among the attributes that business strategists associate with well-designed regulations is flexibility and granting firms compliance latitude. Based on data for all major investor-owned electric utilities in the United States, we evaluate the impact that different categories of environmental-related plant investments have on these utilities' productive efficiencies, which are calculated using data envelopment analysis. Our results, which are based on analysis of firm-level data, empirically demonstrate that regulatory design does make a difference. Our findings suggest that locally-based and administered regulation such as those relating to waste pollution which gives companies more latitude has a more positive influence on productivity than national requirements with inflexible technology-forcing guidelines related to air and water pollution which we find have a negative impact on utilities' productivity.

Key words: corporate performance; data envelopment analysis; electric utilities; environmental regulations; productivity.

1. INTRODUCTION

The United States spends approximately $100 billion a year on pollution abatement and control expenditures (Jaffe, Peterson, Portney and Stavins, 1995; Rutledge and Vogan, 1994). Since 1970, when the modern environmental movement was born, with the enactment of the Clean Air Act, the U.S. has spent over $1 trillion in pollution control. And yet, as Jaffe, Peterson, Portney and Stavins (1995) point out, nearly all the evidence that economists have accumulated points to the fact that such high levels of environmental spending have led to a decline in industrial productivity and in the competitiveness of U.S. firms.

The standard assumption among economists is that environmental regulations impose significant costs and thereby slow-down productivity growth. McGuire (1982), Pethig (1975), Siebert (1977), and Yohe (1979) develop the theoretical arguments. Based on aggregate data, a number of empirical studies (Barbera and McConnell, 1990; Crandall, 1981; Denison, 1979; Gollop and Roberts, 1983; Gray, 1987; Haveman and Christainsen, 1981; Norsworthy, Harper and Kunze, 1979) show that environmental regulations do account for a slow-down in productivity growth. Similar results have been established for Germany (Conrad and Wastl, 1995).

Conversely, a more recent view advanced by Porter (1991) and Porter and van der Linde (1995a; 1995b) is that environmental regulations may actually be good for firms, acting to induce them to utilize alternative operational processes that can improve their productivity. Based on the evidence provided by several case studies (e.g. Basta and Vagi, 1988; Berube, Nash, Maxwell and Ehrenfield, 1992; Dorfman, Muir and Miller, 1992; Parkinson, 1990; Sheridan, 1992; King, 1994), Porter and van der Linde (1995b) conclude that well-designed environmental regulations can, in fact, enhance firms' competitiveness. This point of view has found sympathy with writers on the environment like Vice President Gore (Gore, 1992), with popular press writers like Cairncross (1991) and with strategy scholars (Hart, 1995; Shrivastava, 1995).

It is, however, important to remember that the Porter and van der Linde (1995b) argument hinges on the point that well-designed regulations are likely to enhance productivity. They suggest that if regulations are not well designed, then these regulations are less likely to produce the benefits that they consider possible. There may thus be isolated instances of companies that have made productivity gains in response to regulations. In the aggregate, however, Porter and van de Linde's (1995b) assertions do not seem to be that much different from the arguments made by the economists. The Porter and van der Linde (1995b) understanding of the problem appears to be that one can find isolated instances of several regulations, as now constituted, which induce firms to use their resources more productively. The overall impact of regulations on productivity is, however, only likely to become positive when the regulations are better designed.

The Porter and van der Linde (1995b) criteria for well-designed regulations include flexible approaches that focus on outcomes and not technologies. They argue for policy tools that create economic incentives for innovation, with the locus of decision-making remaining in firms' hands, as opposed to government dictates that mandate outcomes through the choice of technologies and emission levels. Porter and van der Linde (1995b) are especially critical of aspects of the clean air and clean water acts that mandate particular changes in production technology based on government established best available technology standards. These parts of the statutes fail to give firms sufficient decision-making flexibility to choose a method of compliance.

We maintain that a resolution of the controversy between those who assert that environmental requirements retard productivity and those who assert that environmental requirements promote productivity has not advanced because the Porter and van der Linde (1995b) argument has not been correctly understood. Though the difference between the two sides in the controversy should not be minimized, both sides maintain that overall effects of environmental regulation on productivity are likely to be positive only when regulations are well-designed and give corporations choices. Those who assert that environmental requirements retard productivity adopt a neoclassical approach. This approach takes the view that if a change in production process would be better in improving productivity, firms would make the change without regulators pushing them to do it. The Porter and van der Linde (1995b) approach is the claim that regulation might be helpful, but businesses might not have sufficient foresight to identify possible improvements that would result from rethinking their production processes. Slack (Cyert and March, 1963; Thompson, 1967) and x-inefficiency (Leibenstein, 1976) exist within organizations, firms are not necessarily as efficient as they can be, and there is non-profit maximization taking place on part of the business. Government regulations can be flexible rather than restrictive. Once firms are given flexibility, then such a feature of the regulatory process encourages local search by firms so that they become innovative and implement operational changes that do have a positive impact on performance.

Different Types of Regulation Yield Different Results: In this paper, we aim to transcend what has been an apparent dichotomy in the debate by demonstrating empirically that there are different types of regulations, based on the extent to which these regulations give firms latitude. These different types of regulatory requirement have different impacts on firm productivity. We move beyond prior discussions of the issues by using data for major investor-owned electric utilities in the United States and evaluating the relationship between their levels of environmental expenditure on different types of requirements and the impact of these expenditures on productive efficiency of the electric utilities studied.

We focus on productivity, since the use of firms' accumulated resources is of major consequence in gaining competitive advantage, and how well resources are used determines firms' abilities to grow (Majumdar, 1998). The function of resource utilization is as important as resource accumulation and capability building, since the primary capabilities of management are revealed by firms' efficiencies (Hall and Winsten, 1959). Additionally, in the context of the environmental regulations and performance debate, a focus on productivity places emphasis on going beyond merely eliminating firm-level pollution to dealing with lowering true economic cost and making operations efficient and effective (Porter and van der Linde, 1995b).

The choice of electric utilities is useful because they are major polluters, and as regulated public utilities data on performance issues are available. The context, therefore, is apposite in evaluating key issues relating to the firm-level impacts of environmental regulation. By focussing on the different impacts of the different types of regulation, we attempt to move the debate in a constructive direction.

Electric utilities' environmental expenditures are divided into different categories to capture different types of regulatory controls (Percival, Miller, Schroeder, and Leape, 1992). With respect to the stock of capital investments for air and water pollution, electric utilities' choices are severely restricted by statute. In accord with what both economists and Porter and van de Linde (1995b) maintain we would expect to find a negative impact on productivity. With respect to the stock of capital investments electric utilities make for solid wastes, they, however, have greater choices. We would expect to find a positive impact on productivity in such circumstances. To a much greater extent than is the case with air and water pollution requirements, the solid waste regulations are designed with flexibility in mind. Their final form, and administration, is established locally, not nationally. Companies, thus, have more discretion to choose as to how they will comply with the regulations. Thus, the effect of environmental regulations on productivity is likely to be positive, while the effect of the air and water pollution controls on productivity is likely to be negative. It is this relationship that we empirically evaluate in this paper.

This paper unfolds as follows. In the next section the problem is discussed in more detail. We elaborate on the conceptual issues and briefly describe the salient features of our analysis. Thereafter, the empirical context is described. The productive efficiency estimation procedure and the model that helps explain variations in productive efficiency are described as well. Then that is followed by a discussion of the results, a section that develops this study's implications and finally concluding remarks.

2. CONTOURS OF THE DEBATE AND OUR APPROACH

The Problem: The protagonists of the view that environmental regulations have negative productivity consequences start with the premise that government regulations interfere with market processes that otherwise would maximize productivity (Haveman and Christainsen, 1981). In a market economy that operates without distortions, such regulatory interventions cause deviations in output levels that would not be seen in the absence of the regulation. Haveman and Christainsen (1981) and Jaffe, Peterson, Portney and Stavins (1995) advance a number of reasons why productivity is negatively affected by regulatory spending. They demonstrate that achieving higher levels of environmental quality with a given level of factor inputs causes measured productivity, as commonly defined in the economic literature, to fall.

Nevertheless, the emphasis in the aggregate studies on measured output does not capture the contributions to social welfare which environmental regulations are meant to achieve, as pointed out by many observers (e.g. Haveman and Christainsen, 1981). For example, environmental regulations contribute to better health and less demand for medical services, lives that are longer and less plagued by nagging and annoying illnesses, and increased recreational opportunities. This common fault affects studies based on aggregate data.

The micro-level arguments follow. Inputs, such as engineers, for instance, are drawn from the same pool as the input for engineers used in environmental projects. High quality engineers are in short supply. Their deployment on environmental projects results in their withdrawal from efforts that offer greater payback from an economic point of view. Since an output like environmental quality is not recognized as a standard output in typical productivity calculations

(Repetto, 1990), the direct and measurable impact of the withdrawal of the engineers from the economic activities yields a decline in productivity (Gray, 1987).

In addition, when firms change management and operational processes in response to environmental regulations, they may introduce less efficient processes. For instance, energy is dissipated because a scrubber or other pollution control device is added at the end-of-a-pipe. Parasitic power losses associated with scrubbers are estimated to be about 1.5 percent of plant output (U.S. Department of Energy, 1993). There will be operating expenses associated with the scrubber and administrative expenses in monitoring emissions and reporting these emissions to the authorities. Labor and maintenance costs for scrubbers are estimated to be about 2.5 to 3.0 percent of capital costs per year (U.S. Department of Energy, 1993), with a good estimate of the additional revenues needed to pay for a scrubber system being 0.40 cents per kilowatt hour.

Another problem is that many environmental regulations exempt older plant and equipment from requirements. These rules, in effect, penalize newer-generation equipment and discourage or delay investments in newer and more efficient facilities. Economists contend that mandated pollution control investments compete with investments in more productive plant and equipment and thereby crowd them out. The evidence on the crowding-out issue is, however, at best, mixed (e.g. see Rose, 1983). Pollution control regulations also tend to conform to engineering standards rather than business ones, hence inducing capital investments at a higher level of intensity than necessary. As Wells (1984) points out, such investments tend to rely on an engineering approach to a problem rather than an economic one.

An additional charge is that environmental regulations prevent good siting decisions. The need to establish protected areas and to achieve the highest level of technical controls possible keeps companies from siting their plants in locations that are best from an economic point of view. Lengthy permit-acquiring processes add to the inefficiency of developing a new site for a facility. For example, a firm may choose to build a new facility as an expansion to an existing site rather than develop a more efficient greenfield site due to the regulatory hurdles associated with the latter.

The general uncertainty of evolving regulations also involves costs. Environmental legislation increases uncertainty in at least two ways. First, regulation itself is subject to change over time. What is at one time permitted is in the next period prohibited. Plant and equipment may have to be prematurely mothballed. Second, there is the uncertainty of successfully overcoming regulatory hurdles. As the time between when an investment is made and when returns are realized lengthens, return on investment declines. Permit-acquiring procedures have extended the construction timetables in several industries by substantial amounts (Barbera and McConnell, 1990). Anticipating demand farther out into the future makes the decision whether or not to construct a new facility more complicated.

The Porter (1991) and Porter and van der Linde (1995a; 1995b) point of view that environmental regulations may actually have a positive impact on competitiveness is acknowledged as revisionist (Jaffe, Peterson, Portney and Stavins, 1995). This perspective has two elements. First, in the absence of environmental regulations, firms do not know what level of wastes they are producing (King, 1994). Regulations provide a signal about likely resource inefficiencies and potential technological improvements. A second element is that operational efforts undertaken to minimize pollution can spawn changes throughout the firm. Such changes can lead to greater productive efficiency. This hypothesis of productivity enhancement rests on the assumption of organizational slack. This can stimulate the search for methods of reducing organizational slack as well as making the relevant investments that can have long-run efficiency consequences.

The Porter (1991) and Porter and van der Linde (1995a; 1995b) argument is based on certain key premises. Wasteful output, whether tangible output or pollution output which cause externalities, prima facie represents an inefficient use of inputs. Like defects, pollution often reveals flaws in the product design or the production process. Therefore, waste minimization efforts can root out basic production inefficiencies. Those firms that conduct waste minimization efforts, moreover, will be able to privately internalize a significant part of the efficiencies gained. These efficiency gains can come in the form of either production or process improvements. Porter and van de Linde (1995b) suggest that waste minimization efforts also may increase the value of a product by either raising its quality, or by lowering the product disposal costs of the user.

Waste minimization has the potential to induce process improvements that lower the cost of raw materials, their conversion and handling, and waste disposal. Often, the private gains are sufficient to offset the expenditures. For example, in an assessment of prevention of waste generation efforts at 29 chemical plants, Porter and van der Linde (1995a) report that 180 out of the 181 activities resulted in a net cost decrease. Only one activity increased costs. In a study of operational processes change in 10 manufacturers of printed circuit boards, the pollution control staff initiated 12 of the 13 major changes which resulted in cost reduction (King, 1994). The motivating factors behind the prevention of waste were high because of the high waste disposal costs and the presence of environmental regulations.

A difference between Porter and van der Linde (1995b) and the more conventional economic studies that preceded them is that Porter and van der Linde (1995b) are focusing on the resource productivity enhancements that can flow from investments in pollution prevention. The prior studies, on the other hand, have emphasized the costs of investing in expensive pollution control devices that abate pollution at the end-of-a-pipe. Pollution prevention helps improve productive efficiency by addressing the root causes that give rise to pollution in the first place. One way of doing this is the substitution of either cheaper or better materials, or the better use of existing materials. Forced to comply with regulations to reduce solvent emissions radically, 3M, for instance, found that in some processes it could avoid solvent usage altogether. Dow Chemical, in another example, redesigned the way it used caustic soda for annual savings of over $20 million (Dorfman, Muir and Miller, 1992).

Prevention, then, rather relying on wasteful add-on devices, leads to productivity enhancements. Du Pont, for instance, when faced with cost increases from regulatory implementation, installed higher-quality waste monitoring equipment which reduced production interruptions and down-time (Parkinson, 1990). Similarly, Ciba-Geigy replaced iron with a different chemical conversion agent in the production of dyestuff and boosted yields by 40 percent. This initiative led to annual cost savings of $750,000 (Dorfman, Muir and Miller, 1992).

In sum, the Porter and van der Linde (1995b) argument is that properly designed regulatory regimes can create pressures for undertaking investment in cost-saving pollution prevention in general. Environmental regulations, if well designed, can provide the pressure for firms to undertake these cost-saving investments and to look for ways to enhance their operating efficiencies (Porter and van der Linde, 1995a). Greenstein, McMaster and Spiller (1995) provide evidence that well-designed regulations influence firms to make cost-saving investments in the U.S. telecommunications industry, and Majumdar (1997) provides evidence about the productivity consequences arising from well-designed regulations, again for the U.S. telecommunications industry.

The Evidence: While the theoretical arguments of the protagonists in both camps, the economists and Porter and van de Linde (1995b), have some validity, the empirical evidence on the basis of which the conclusions of either perspective have been reached is very different. Those who argue that environmental regulations are harmful for competitiveness do so on the basis of aggregate data. National cross-industry environmental expenditures do turn out to be negatively related to national cross-industry measures of competitiveness. Conversely, those like Porter and van der Linde (1995b) who argue that environmental regulations may actually be good for firms tend to do so using studies based on anecdotal evidence involving a single or a few incidents in a firm or industry. In these cases, the disaggregation problem is severe. This arises because of small sample bias, and the fact that there is the problem of sample selectivity. Supporters of the Porter and van der Linde (1995b) argument can look for examples that confirm their beliefs, and firms will tend to publicize success more than failures.

In the few studies (Hart and Ahuja, 1996; Russo and Fouts, 1997) that have aggregated data for analysis at the relevant level of the firm, the emphasis has been on measures of profitability, not productivity. These studies find a positive relationship between environmental requirements and profitability, especially in circumstances of firms with high prior pollution (Hart and Ahuja, 1996) and greater growth (Russo and Fouts, 1997). The key productivity issue in the controversy between Porter and van der Linde (1995a; 1995b) and the economists is, however, just not addressed. Moreover, in the chain of performance causation, productivity occurs prior to profitability (Banker, Chang and Majumdar, 1996). Hence, no matter how many controls are introduced into the statistical models by authors (Hart and Ahuja, 1996; Russo and Fouts, 1997) there are too many factors confounding profitability to arrive at a meaningful conclusion.

A recent piece by Jaffe and Palmer (1997), who belong to the economists' camp, attempt to test Porter's hypothesis by evaluating the environmental regulations and innovation linkage, an issue on which considerable theoretical literature exists but empirical evidence is absent. Jaffe and Palmer (1997) claim that Porter's hypothesis has a "narrow" version in which certain types of environmental regulations stimulate innovation. They further suggest that almost all existing U.S. environmental regulation is not of this type, since these regulations prescribe both the processes required to be undertaken as well as the goals of the regulation. They also claim that a "weak" version of the hypothesis exists in which regulations stimulate certain kinds of innovations. Environmental regulations place constraints on the profit opportunities of firms that were not there before. Firms attempting to maximize profits will, therefore, attempt to undertake a set of activities that will lead to cost reductions.

Jaffe and Palmer (1997) test the environmental regulation and innovation linkage by evaluating the relationship between environmental expenditures, R&D spending and patents. They find that there is a significant and positive relationship between environmental regulation compliance expenditures and R&D spending, even on the basis of aggregate industry-level data, but a similar relationship is not established between environmental regulation compliance expenditures and patents. They reach the conclusion that Porter's "weak" hypothesis of environmental spending stimulating innovation is, indeed, supported by the data. Therefore, the only extant study to explicitly test Porter's hypothesis, albeit in a limited manner, finds that the evidence is consistent with some of the postulates advanced by Porter.

Our Approach and Hypothesis: Our intention is to understand the productivity effects of pollution regulation. The electric utility industry provides a key test setting. The reasons for studying this industry are its large impacts on the environment. The Environmental Protection Agency (1993) estimates that the industry generates 70 percent of all U.S. sulfur dioxide emissions and 30 percent of all U.S. nitrogen oxides. It is a major contributor to greenhouse gases, emitting more than 500 million tons of carbon per year (EPA, 1993).

Only one prior study has examined the effects of environmental regulations on electric utilities' productivity. Gollop and Roberts (1983) found a very large and negative effect, which Jaffe et. al. (1995) calculated to be the largest negative impact of environmental regulation on productivity in any industry. The percentage share reduction in productivity due to environmental regulation was 44 percent compared to an 8 to 12 per cent drop in productivity in other industries. These findings, however, came from a period when overall business conditions were very different. Severe inflation, high unemployment and a concern about national energy shortages marked the business cycle. Gollop and Roberts (1983) attributed the impacts to fuel prices, but fuel prices are now very different (Marcus and Geffen, 1997).

We calculate productive efficiency for the firms in the electric utility and regress this measure on a set of variables capturing environmental spending as well as control variables that capture other aspects of electric utility operations. The year 1990 is chosen for analysis because it is prior to the implementation of major new air pollution legislation. This 1990 amendment to the clean air act introduces a pollution trading scheme that changes the utilities' incentives to invest in pollution control equipment. The new laws are a mixture of traditional command and control rules and include some incentive regulation elements. Up to 1990, the clean air act is more purely command and control in nature and orientation. Thus, it is a better year to test the argument that less flexible regulation tends to retard productivity, while more flexible regulation tends to enhance it.

Solid waste laws in effect in 1990 allow for more flexibility. They are administered at a local and not the national level because the remains from fossil fuel combustion are specifically exempted from the hazardous waste category. Responsibility for regulating non-hazardous wastes is assigned to the states subject to minimum federal standards. These requirements show greater variation and less rigidity than the air and water pollution control laws. By being better adapted to local conditions, they give utilities more choice and the chance for better economic outcomes.

The utilities, depending on local conditions, have been able to pursue recycling programs of varying degrees of economic benefit depending on how close they are to local markets and how much demand there is for the recycling products. The fly ash that remains from coal combustion can be made into gypsum and the bottom ash can be made into concrete. They can only be sold locally. They cannot be transported long distances economically because they weigh too much. The utilities also can build and operate their own ash ponds, landfills, and other systems to manage their wastes, or they can pay someone else to transport, manage, and dispose of the wastes. This choice is akin to the perspective in the Williamson (1975) transaction costs economics concept between the decision to make a good or service oneself or to purchase it from an outside party.

This level of choice is not available in the case of air and water pollution control. Firm discretion is more constrained. The options for handling these wastes are more limited. In the case of air and water pollution control, Congress has pursued a deliberate technology forcing strategy. Emitters have been forced to conform to technology-based standards or else face closure. In the case of air pollution, they have been subject to stringent best available control technology (BACT) and lowest achievable emission rate (LAER) standards. These standards have been technically determined by the Environmental Protection Agency, with economics not being allowed to enter into the calculation.

In the case of water pollution control, the same type of technology forcing strategy is in effect. Emitters have had to comply with what has been put forward as technologically feasible.

The expectation is that they will rely on Best Available Technology (BAT) end-of-pipe (EOP) treatment. BAT is defined by Environmental Protection Agency as the "very best control measures that have been or are capable of being achieved" (Percival, Miller, Schroeder, and Leape, 1992). The Environmental Protection Agency determines a BAT standard for each industry, and then, under the National Pollution Discharge Elimination System (NPDES), it establishes specific levels of performance for every discharge. The Environmental Protection Agency then provides strict mechanisms to assure compliance. In other words, an engineering approach (Wells, 1984) dominates the implementation of air and water pollution regulations, as opposed to an economic approach that characterizes waste pollution management.

Our argument is that these different regulatory designs lead to different economic results. The air and water pollution regulations act to retard utility productivity, while the solid waste requirements enhance it. The difference between these sets of requirements is in the degree of flexibility they allow. More flexible regulations, like those relating to solid waste, have the potential to increase productivity, while the less flexible ones, like the air and water regulations, can suppress or make a negative impact on productivity. Thus, we hypothesize the following: the null hypothesis - H_0 - is that there are likely to be no observed differences between various types of environmental regulatory expenditures and utilities' productivity. The alternative hypothesis - H_1 - is that air and water pollution control expenditures will have a negative effect on productivity, while solid waste expenditures will have a positive effect.

3. EMPIRICAL ANALYSIS

Sample: The U.S. electric utility industry consists of 3,241 firms. Of these firms, 267 firms are owned by private investors, 2,011 firms are publicly owned by state and municipal authorities, 10 firms are federal owned and 953 firms are organized as cooperatives. While these 267 investor-owned utilities account for only 8 percent of the electric utilities in the nation, they account for 79 percent of all revenues from sales of electricity to ultimate consumers.

The economic behavior of a critical mass of firms in the U. S. electric utility industry is evaluated. Our sample has full cross-sectional variation and accounts for a large percentage of electric power production and distribution in the United State. In 1990, the year used for the empirical study, the total revenues of the investor-owned utilities in the U.S.A. were $155 billion. Of these 267 companies, 150 utilities with total revenues of $150 billion are studied. The source of data is the Federal Energy Regulatory Commission's Statistics of Investor Owned Electric Utilities. Productive efficiency is first estimated, and then variations in such firm-level productive efficiencies are explained using regression analysis where environmental spending variables are the primary regressors. This approach is consistent with prior work (Majumdar, 1997).

Estimating Efficiency: Productive efficiency is estimated for the 150 investor-owned utilities, using the data envelopment analysis model of Banker, Charnes and Cooper (1984) [BCC]. Following past research on investor-owned utilities (e.g. Banker, 1984; Nelson, 1989; Roberts, 1986) the output used is the total sales and dispositions of energy in mega-watt hours. Key multiple inputs used are: total production plant, total transmission plant, total distribution plant, total general plant, the number of employees and purchased power. The use of these six inputs: various types of capital, labor and externally purchased power enable these utilities to distribute and sell electric power to consumers throughout the United States.

Data envelopment analysis takes into account observation-specific factors in the computation of a firm-level resource utilization measure. Charnes, Cooper and Rhodes (1978) [CCR] develop, while Banker, Charnes and Cooper (1984) and Charnes, Cooper, Golany, Seiford and Stutz (1985) [CCGSS] extend the Farrell (1957) measure of efficiency to a multiple output-input case using a fractional mathematical program, which is translated into a linear-programming formulation.

Data envelopment analysis helps ascertain firm-level differences in resource utilization. It is a technique that converts multiple input and output measures into a single measure of relative performance for each observation in a data set. The ratio of the weighted outputs to weighted inputs of each observation is maximized. This is a measure of performance that captures how efficient each observation is in converting a set of inputs jointly and simultaneously into a set of outputs. Data required for computational purposes are an output vector $\mathbf{Y_r} = (y_{1j}, y_{2j}, \ldots\ldots y_{rj})$, of outputs $r = (1, 2, \ldots\ldots R)$, for observations $j = (1, 2, ..k....N)$ and an input vector $\mathbf{X_i} = (x_{1i}, x_{2i}, \ldots\ldots x_{ij})$, of inputs $i = (1, 2, \ldots\ldots I)$, for each of the j observations.

The generalized DEA model is presented by the following formulation:

Max $e_{k,k}$ (1)

subject to:

$e_{j,k} \leq 1, \forall j;$

$\mu_{rk} \geq \epsilon, \forall r;$

and $v_{ik} \geq \in$, $\forall$ I;

where $j > 1,....n$ is the index for observations, k being used as the index for the observation being specifically evaluated and $e_{k,k}$ is the efficiency score for that observation, $r = 1,....R$ is the index for the outputs ($y_{rj} \geq 0$ is output r of observation j), $i = 1,....I$ is the index for the inputs ($x_{ij} \geq 0$ is input i of observation j), $e_{j,k}$ is the relative efficiency of observation j when observation 0 is evaluated, μ_{rk} and v_{ik} are the output and input weights, respectively, associated with the evaluation of observation k, and $\in$ is a non-Archimedean infinitesimal quantity. In (1), the input (x_{ij}) and output (y_{rj}) factors are known quantities observed from the activities of the observations, the factor weights (μ_{rk} and v_{ik}) are the decision variables and the CCR DEA model can be defined as:

$$e_{j,k} = \sum_{r=1}^{R} \mu_{rk} \bullet y_{rj} / \sum_{i=1}^{I} v_{i0} \bullet x_{ij} \qquad (2).$$

Linear-programming based approaches used in empirically evaluating economic phenomena have been subject to a constant returns to scale constraint, a condition useful for theoretical purposes but not of practical use. The original Farrell and the CCR models do also incorporate this constraint. Banker, Charnes and Cooper (1984) show that the constant returns to scale constraint implicit in the CCR model can be relaxed. The BCC algorithm assumes that variable returns to scale exist for firms. Thus, a variable u_0 is added in the programming formulation so that the hyperplanes for each observation do not pass through the origin, while in the CCR model hyperplanes pass through the origin because constant returns to scale are assumed. In the constraint set for the linear programming model, this variable is kept unconstrained. Thereby, it can take on values, depending on the data, which are negative [denoting that increasing returns to scale may exist], 0 [denoting that constant returns to scale may exist] or positive [denoting that decreasing returns to scale may exist], for each j^{th} observation. The CCR model generates a total efficiency score comprising a scale efficiency component and a technical efficiency component, while the BCC model generates a technical efficiency score.

The optimization in (1) is repeated n times, once for each observation in the data-set for which efficiency is to be evaluated; thus a separate evaluation of efficiency is carried out for each k^{th} firm-level observation. Each time the optimization is carried out, data for all j observations form part of the constraint set, so that the observation is compared against all others in the data set. The constraint in (2) implies that the efficiency of any other observation in the constraint set cannot be greater than 1. Constraints number (3) and (4) imply that there cannot be any negative inputs and outputs. The objective function values obtained partition the data set into two parts: one part consisting of efficient observations which determine an envelopment surface or frontier; the other part consisting of firms which are inefficient and for which $e_{k,k} < 1$.

Charnes, Cooper, Lewin and Seiford (1994) and Seiford and Thrall (1990) contain detailed technical material, discussions of the various models feasible within a DEA framework, software availability and applications of DEA, as well as discussions of the extensions to performance analysis that have taken place within a DEA framework. The empirical applications literature on DEA is also now large. There are over 1,000 pieces available in the literature.

The weights, μ_{rk} and v_{ik}, are determined each time the optimization in (1) is carried out. Based on data, the DEA procedure takes each observation's idiosyncrasies into account in evaluating efficiency. The computation of weights is based on a determination of which input(s) a particular observation is adept at utilizing, or which output(s) it is adept at in generating. By assigning high weights to the input and output variables an observation is adept at in utilizing or generating, and low weights to the others, the algorithm maximizes the observed performance of each observation in light of its particular capabilities.

Data envelopment analysis involves the construction of a piece-wise linear frontier. Given data, the algorithm identifies sets of firms based on production characteristics as defining one portion of this piece-wise frontier. Each non-efficient firm belongs to one of these sets, and the efficient firms from each such set defines the hypothetical comparison unit (HCU) for a non-efficient firm. The identification of sets is complex because the algorithm performs a non-linear optimization where there are multiple output and input variables. Contrast this with basic multiple regression analysis in which there is a single linear optimization with one dependent variable, but multiple independent variables. This optimization is undertaken as many times as there are numbers of observations in the data set. After all optimizations are complete, the algorithm groups together firms based on similarities in production correspondences. If different inputs and outputs are used for the same data set, different referent sets will emerge because production correspondences between different variables are not the same.

For non-efficient firms, the algorithm reveals the precise quantity for each input that it should have consumed, if it were to be as efficient as its HCU. In other words, given the output produced, the inefficient observation could have consumed that much less of the input in question, without a loss in any of the outputs produced. The quantification of the over-consumption of different inputs can pinpoint the specific inputs in respect of which the firm's strategies for utilization ought to be re-assessed. This attribute permits firm-level strategic benchmarking.

A number of features of DEA provide advantages for empirical research. Data envelopment analysis handles multiple outputs and inputs simultaneously and deals with the use of joint inputs to produce joint outputs. No assumptions about functional form other than convexity and piece-wise linearity are made. Data envelopment analysis makes no assumptions as to the technology used by firms. The DEA algorithms generate coefficients that vary by firm. Data envelopment analysis is oriented to frontiers estimation rather than estimation of central tendencies. Data envelopment analysis optimizes for each individual observation while regression approaches are averaging techniques that proceed via a single optimization to arrive at a single parameter across all observations. The use of DEA can, however, be limited by the data used.

Data envelopment analysis is an extremal methodology and outliers supplied to generate the frontier can bias the results. Data on inputs and outputs among observations should be comparable. Data envelopment analysis results are applicable with respect to the firms for which data have been used in generating the results. Also, the frontier firms identified based on the analysis of one data set may not necessarily be operating at the theoretically attainable frontier. Data set design can be static or dynamic. The CCR measure of efficiency consists of managerial efficiency and scale efficiency components. Banker, Charnes and Cooper (1984) decompose the CCR measure into managerial efficiency and scale efficiency components. This is useful for contemporary firm-level research because firms' returns to scale characteristics are allowed to vary, which is in consonance with empirical realities.

Regression Model: To evaluate the impact of environmental regulatory factors on productive efficiency of electric utilities, the regression model estimated is *ln EFFICIENCY = f (AIR POLLUTION; WATER POLLUTION; WASTE POLLUTION; NOISE POLLUTION; ESTHETIC POLLUTION; SIZE; R&D; RESIDENTIAL; NUCLEAR)* (3).

In the above model *ln EFFICIENCY* is the natural log of the efficiency score for the i^{th} electric utility (i = 1, 2, 3,....150), *AIR POLLUTION* is the ratio of air pollution plant to total utility plant, *WATER POLLUTION* is the ratio of the water pollution plant to the total utility plant and *WASTE POLLUTION* is the ratio of the waste pollution plant to the total utility plant. These are the principal explanatory variables capturing utilities' investment exposure to different types of pollution control activities.

Subsidiary environmental spending variables are as follows: *NOISE POLLUTION* and *ESTHETIC POLLUTION* control for the stock of investment exposure towards the prevention of noise pollution as well as the stock of investments required to maintain the ambiance of the utilities' external premises. Because much of the prior empirical literature has evaluated environmental spending in the aggregate, we also estimate a model where the variable *TOTAL POLLUTION* is the ratio of total environmental plant to total plant. The use of abatement capital stock to capture environmental spending is consistent with the literature reviewed by Jaffe, Peterson, Portney and Stavins (1995). Some examples of this empirical literature are Barbera and McConnell (1990), Conrad and Wastl (1995), and Jaffe and Palmer (1997) who argue that capital stock values are better measures of environmental expenditures incurred than annual operating and capital expenditures, since the latter categories of expenditures involve smoothing.

Additional variables control for other facets of electric utilities' activities that affect productivity. The variable *SIZE* captures utility size using the natural log of total sales or revenues. In the electric utility industry the relevant evidence (Atkinson and Halvorsen, 1984; Gegax and Nowotny, 1993; Nelson and Primeaux, 1988; Roberts, 1986) suggests that the size and productive efficiency relationship is positive. The variable *R&D* is the ratio of research and development expenditures to total operational expenditures. It is a key important control variable since the R&D productivity linkage is considered as important in the literature on productivity (Griliches, 1988). This measure is, however, less precise than a measure of R&D stock that we are unable to calculate.

Density effects are important in influencing electric utilities' performance with respect to transmission activities. Where customers are large and concentrated, costs are lowered. This is true particularly where distribution to business users is concerned (Salvanes and Tjotta, 1994). The variable *RESIDENTIAL*, which is the ratio of residential customers to total customers, controls for such distribution network density effects. Nuclear power production accounts for a fifth of electric power produced in the United States, and Kamerschen and Thompson (1993) find that nuclear power generation leads to efficiencies relative to fossil-fuel based power generation. As important as this controversial finding is, using nuclear as a control allows us to focus on the fossil fuel generating units of the utilities where air, water, and solid waste pollution are most relevant. The variable *NUCLEAR* is the ratio of nuclear power production expenses to total operating expenses, and proxies for the approximate proportion of nuclear power generated by each utility.

Results: The efficiency scores derived using DEA range from a minimum of 0.32, on a scale of 0 to 1, to a maximum of 1.00. The mean score for the 150 electric utilities is 0.78; however, the standard deviation of the score is 0.24, with an associated coefficient of variation of 0.29. There is a relatively large amount of heterogeneity in the sample of electric utilities as to how efficient they are. Additional evidence of heterogeneity is available from a review of the inter-quartile deviation for the efficiency score, which is 0.42.

The primary regression results are presented in Table 1. First, the model, where the dependent variable is the natural log of productive efficiency and the regressors are environmental spending as well as control variables, is estimated using ordinary least squares (OLS). Tests of heteroscedasticity are carried out, because in the presence of heteroscedastic error terms the estimates are unbiased but no longer efficient. The results reveal the presence of heteroscedasticity using the Breusch and Pagan (1979), the Godfrey (1978) and the Glejser (1969) tests, and based on the χ^2 statistics we reject the null hypothesis of homoscedasticity at the 5 percent level of significance.

Second, studentized residuals are identified from the initial OLS estimation. These studentized residuals help identify outliers and have an approximate *t* distribution with n-p-1 degrees of freedom (Belsley, Kuh and Welsch, 1980). The model is then re-estimated using a heteroscedasticity correction procedure for all the 150 observations as well as after omitting outlier observations that have a residual with an absolute value of 1.96 or more. The re-estimated regression results, after dropping the outliers, remain the same as the results obtained using 150 observations corrected for heteroscedasticity using the maximum likelihood estimation procedure

(Davidson and MacKinnon, 1993) for the heteroscedasticity correction. The reported results use data for all 150 observations.

The results show clearly that in the case of air and water pollution expenditures the impact on utilities' productivity is negative. The variables *AIR POLLUTION* and *WATER POLLUTION* are significant and with the p values of the t ratios being < 0.05 and < 0.001 respectively. In the case of solid waste expenditures the impacts on productivity is significantly positive, with the p value for the t ratio for *WASTE POLLUTION* being < 0.001. In other words, on average the greater the level of plant that is dedicated to waste pollution in electric utilities, the higher is their productive efficiency. The opposite relationship is true when plant is dedicated to air and water pollution prevention. The variables *NOISE POLLUTION* and *ESTHETIC POLLUTION* are included as controls because we are interested in the disaggregation of environmental spending into all possible sources of expenditures. These variables turn out to be negative, and *ESTHETIC POLLUTION* turns out to be significant with a p value that is < 0.05. Based on the results, we can reject the null hypothesis.

Interestingly, when the variable *TOTAL POLLUTION* is alone introduced as a regressor the coefficient estimate is negative and significant at $p < 0.05$. The magnitude of the coefficient, however, is not large. These results imply that when the impact of environmental regulations is evaluated at a highly disaggregated level of analysis, as it ought to be, the impact of some types of regulations are, indeed, positive as our primary results show. Nevertheless, the overall impact of aggregated environmental expenditures on productivity may turn out to be negative. This aggregation problem has, by and large, plagued most of the extant empirical studies evaluating the environmental expenditures and productivity linkage.

What is the relative impact of different types of environmental expenditures on productivity? We estimate the standardized coefficients for each regressor variable. First, we note that of the two negative pollution abatement variables *AIR POLLUTION* has less of a negative impact on productivity than *WATER POLLUTION.* The standardized coefficients of these variables are -0.062 and -0.120 respectively. The impact of these variables, however, is considerably over-shadowed by the magnitude of the impact of *WASTE POLLUTION* for which the standardized coefficient is 0.212. When *TOTAL POLLUTION* is introduced as a single regressor in a separate model, the magnitude of its impact is not high, with the standardized coefficient being -0.052.

Of the control variables, *SIZE, R&D* and *RESIDENTIAL* are significant and of the generally expected sign. These results are consistent with theory and institutional expectations. The relative impacts of *SIZE, R&D* and *RESIDENTIAL* on productivity are quite substantial, as the magnitude of the standardized coefficients show. These are 0.101, 0.151 and -0.289 respectively. *NUCLEAR* is positive in both equations, but significant in one, this result being consistent with expectations.

Our dependent variable, which is the productive efficiency of each electric utility, ranges between 0 and 1. Therefore, the distribution is censored. In our regression estimation the dependent variable is expressed in logs because taking the log of a half-normally distributed variable ranging between 0 and 1 makes the resulting distribution log normal. An alternative way to approach the censoring problem is to estimate a Tobit model (Davidson and MacKinnon, 1993).

We calculate the relative inefficiency of each observation as 1 minus the efficiency score. Perfectly efficient firms, therefore, have an inefficiency score of 0. These are the observations at the limit. Thereafter, to what extent the various regulatory expenditures determine the relative inefficiencies of the utilities are estimated using a Tobit model. Table 2 provides the Tobit estimates of the determinants of inefficiency. Now, if a coefficient estimate is negative that means the variable has a positive impact on efficiency. The variables *AIR POLLUTION* and *WATER POLLUTION* are both positive, signifying that they have a negative impact on efficiency; in other words, firms which spend more on these items are inefficient relative to the other firms. In the case of solid waste expenditures the impacts on inefficiency is significantly negative, with the p value for the t ratio for *WASTE POLLUTION* being < 0.05. Again, using an alternative method of estimation, spending more on waste pollution makes firms more efficient relative to the other utilities.

4. IMPLICATIONS

The electric utility industry context provides a useful testing-ground to evaluate the effects of environmental regulation on industry productivity, given the existence of different regulatory constraints and structures. In this sense, the policy environment of the electric utilities enables us to examine Porter and van der Linde's (1995b) condition about the circumstances under which environmental regulations can have a positive effect on productivity. Either utilities are legally bound to install a particular technology, for example an end-of-pipe add-on device like a scrubber or a water cooling tower, and pay a heavy price for it, or they have greater discretion to fashion a regulatory response that is sensitive to different local conditions.

For instance, electric utilities can recycle and build and operate their own ash ponds, landfills and other solid waste recovery systems to handle their wastes. They can do so on their own, or pay someone else to recycle, transport the waste offsite, and dispose of it in a waste treatment or management facility. This choice of how to handle wastes is akin to the perspective in Williamson's transaction cost economics between the decision a firm faces to make something by itself or purchase it from an outside party or agent. This is a fundamental choice that a firm has. It is a choice that Williamson (1975) has argued is related to differences in firms' productivities.

Since the choice of how to handle the installation of pollution control equipment is so fundamental, the different levels of choices incorporated into the legal frameworks for air and water pollution control, on the one hand, and solid waste control, on the other, should yield different results. The design of regulation, in the way that it affects the choice of how and what pollution control equipment is installed should affect whether environmental regulation retards or enhances productivity. Thus, our hypothesis that air and water pollution control expenditures will have a negative effect on utility productivity, while solid waste expenditures will have a positive impact, has been borne out by the empirical results.

Until the passage of new clean air legislation in 1990, the main regulatory challenges that electric utilities have faced have come from extremely restrictive old-style command and control requirements that were technology forcing. The use of add-on devices such as scrubbers in the case of air pollution and cooling towers and other devices in the case of water pollution has been mandated, leaving firms little room to maneuver or allowing utilities discretion. The flexibility to innovate has been missing and, unlike the chemical and other process industries, the electric utilities have had few opportunities for pollution prevention in air and water pollution. Porter and van der Linde (1995b) would be hard pressed to find air and water pollution prevention success stories in this industry that are similar to the success stories found in other industries.

As we have indicated, in the case of air and water pollution an electric utility has often had no choice but to invest in an add-on device like a scrubber or a cooling tower. Thus, they have had to incur the capital costs that are necessary to do so, though there are no intra-firm economic benefits of doing so. Its choices have been stark and simple because these have been sharply limited by legal mandates that came from the federal government. Because of the large environmental impacts of the utilities, especially in the area of air quality, the federal government was not about to give them much discretion.

In the case of solid wastes electric utilities have been granted much more latitude. Regulation has been at a local level and it has varied from one region to another. The choices a utility has faced have not been as stark. These decisions have been affected by unique local factors. They have depended on such factors as: what are the local markets for gypsum and cement? How far might these recycled products have to be transported? Does the utility have excess space on a production site for a waste disposal facility like an ash pond or landfill? What have been the charges of companies transporting waste? How far would the waste have had to be hauled? How stringent have been local governments in regulating disposal sites? To what extent have they subsidized these sites? What kinds of liability laws have applied in a jurisdiction? How stringently have they been applied? How much competition has there been among companies bidding to handle waste? And, how confident has the utility been in its own ability to construct a facility like a landfill and internalize the long-term costs of dealing with the waste? Factors like these have had no relevance in the case of the overly prescribed air and water pollution requirements, but they have been very relevant considerations in the case of solid wastes.

Because of the possibility for turning solid wastes into raw materials, an alternative interpretation of the positive relationship between productivity and solid waste plant expenditures is feasible. It is likely that the more productive utilities are more likely to take advantage of profitable opportunities for converting waste into usable products. Therefore, they will spend more than other firms on solid waste plant. While this can be the case, the outcome is still a higher level of productivity. In a dynamic context, the additional spending on better plant leads to operational efficiencies and cost-savings. This is only likely to enhance competitiveness, and not retard it.

Given the controversy about the impact of environmental regulation on industrial productivity, these policy differences are extremely interesting. The main condition set by the Porter and van der Linde (1995b) argument about when environmental requirements can contribute to productivity is that there be options available to industry. Without options available, firms cannot figure out how best to minimize wastes and prevent pollution. With the heavy hand of government forcing an end-of-pipe technology solution, there is little likelihood that regulation will be productivity enhancing. Without this heavy hand of government present, firms can figure out how to best handle their wastes and can arrive at efficient solutions that add to, rather than detract from, their productivity. These solutions involve capital investments that enhance efficiencies. Even if productivity might suffer in the short-run, the Porter (1991) argument works in a dynamic long-run context. Existing firms subject to flexible regulations that give them choices develop advantages in new technologies and services. These advantages will become relevant as electric utility sector is fully opened up to the forces of competition.

5. CONCLUSION

In this paper we have shown that the apparent controversy between economists and Porter and Van der Linde (1995b) begins to dissolve when consideration is given to regulatory design. Some regulations inhibit productivity. Others have the potential to enhance it. The key difference is the extent to which the regulations grant firms compliance discretion. With more compliance discretion win-win outcomes of the kind Porter and Van der Linde (1995b) advocate are possible. With regard to the importance of regulatory design, there is little disagreement between the different points of view that have been articulated in the literature.

Environmental regulation is ultimately justified in many if not most cases by recognition of costs that are externalities from the standpoint of the corporation and do not contribute directly to productivity for the firm. That said, the issue of how environmental regulations can be best designed to achieve its desired effects with the least negative, and in some cases even the most positive, effect on productivity remains open. Resources are limited, and these have to be best utilized. In a world in which increasing attention is being paid to plant emissions, industrial competitiveness is ultimately served, from a strategic perspective, by developing and applying potentially state-of-the art industrial processes.

Policy makers have to take regulatory design ever more seriously as society faces diminishing resources, and trade-off between economic and environmental outcomes become more threatening. They do not have the luxury that they have had in the past to opt for environmental stringency regardless of the cost. However much this strategy made sense in the early stages of environmental advocacy, in today's world the need for environmental improvement must be carefully balanced with the need for economic development.

The option to design regulations with flexibility in mind fortunately exists and will have to be relied on more frequently as the benefits of environmental improvement spread to more areas through the globe. Sustainability, which we construe as a sound economy based on environmental protection and equity, is more likely to be realized if a strategy of giving microeconomic agents such as firms flexibility is taken into account and made a part of environmental policy.

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TABLE 1: REGRESSION RESULTS

Dependent variable: Log of Efficiency Score				
	Coefficient Estimate (Standard Error)	Standardized Coefficient	Coefficient Estimate (Standard Error)	Standardized Coefficient
Constant	-0.370***	0.000	-0.370***	0.000
	(0.107)		(0.107)	
AIR POLLUTION	-0.004*	-0.062		
	(0.001)			
WATER POLLUTION	-0.018***	-0.120		
	(0.005)			
WASTE POLLUTION	0.063***	0.212		
	(0.008)			
NOISE POLLUTION	-0.003	-0.001		
	(0.036)			
ESTHETIC POLLUTION	-0.007*	-0.099		
	(0.003)			
TOTAL POLLUTION			-0.002*	-0.052
			(0.001)	
SIZE	0.026**	0.107	0.028*	0.116
	(0.009)		(0.001)	
R&D	0.049***	0.151	0.049***	0.150
	(0.006)		(0.005)	
RESIDENTIAL	-0.885***	-0.289	-0.886***	-0.289
	(0.086)		(0.078)	
NUCLEAR	0.155*	0.069	0.087	0.039
	(0.075)		(0.079)	
α	0.679***		0.692***	
	(0.054)		(0.055)	
Log Likelihood	-1842.390		-100.315	

*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; the estimates are corrected for heteroscedasticity

TABLE 2: TOBIT ESTIMATES OF DETERMINANTS OF INEFFICIENCY

Dependent variable: Inefficiency				
	Normalized Coefficient (α vector)	Asymptotic Standard Error	Regression Coefficient (β vector)	t Ratio
Constant	0.317	1.035	0.101	0.307
AIR POLLUTION	0.024	0.022	0.006	0.934
WATER POLLUTION	0.064	0.057	0.020	1.114
WASTE POLLUTION	-0.220*	0.108	-0.070	2.042
NOISE POLLUTION	0.105	0.652	0.034	0.161
ESTHETIC POLLUTION	0.105	0.020	0.004	0.736
SIZE	-0.069	0.084	-0.022	0.737
R&D	-0.268*	0.130	-0.085	2.066
RESIDENTIAL	3.327***	0.937	1.065	3.549
NUCLEAR	-0.565	0.717	-0.181	0.788
Log Likelihood	-72.695			

*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$