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POLITICAL ECONOMY, COST AND EFFICIENCY ASPECTS OF MARKET-BASED REGULATION:
THE CASE OF TRADEABLE PERMITS UNDER THE CLEAN AIR ACT AMENDMENTS OF 1990

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DEDICATION

To my Parents
Mother. Mary and Father. Milanius
with Love !

ABSTRACT

Market-based economic instruments have become increasingly important as alternatives to conventional methods of environmental regulation, as public policy makers are increasingly aware of the ineffectiveness of command and control regulation. A remarkable breakthrough in the search for lasting solutions to pressing environmental problems is the emergence of the tradeable permits. They recognize the need for establishing property rights prior to addressing the issues of environmental degradation, and offer solutions that are cost-effective, without requiring complex technical information about industry structures to monitor compliance.

However, the current literature provides little guidance for evaluating the overall effectiveness of this new economic instrument. The lack of simultaneous emphasis on all of the important dimensions of market-based regulation led to conflicting views among economists as to the significance of tradeable permits, and the circumstances under which they perform effectively. In an attempt to resolve these different viewpoints, this dissertation undertakes an in-depth inquiry into three fundamental facets of tradeable permits, namely ***political economy aspects, cost aspects and efficiency aspects****. The primary emphasis is on the U.S. SO_2 emissions trading program which was accompanied by the Amendments to the U.S. Clean Air Act in 1990 (CAAA).*

Using a political economy framework, the dissertation examines the institutional dimensions of tradeable permits, and explores how they influence the instrument choice at different stages of the policy making process. The investigation uncovers a number of important linkages of political, social, legal and market conditions, whose interactions determine the desirability of market-based economic instruments over other alternatives. Using examples mainly from the United States, it demonstrates how the performance of tradeable permits depends on situation-specific characteristics of the above factors.

The dissertation then considers the cost aspects of the tradeable permits in order to elucidate the behaviour of the affected firms, and to resolve conflicting views of the potential effects of the tradeable permits on the production costs of regulated industries. The investigation is based on an econometric framework and a large-scale data set representing coal-fuelled electric utilities operating in the United States. It reveals that there has been an upward pressure on the production costs of electric utilities in the aftermath of the CAAA, and that as a result, the utilities have adjusted their optimal mix of inputs by shifting away from pollution-intensive inputs.

The empirical analysis of market-based regulation then explores efficiency aspects of tradeable permits, based on Data Envelopment Analysis (DEA) and a Tobit model. This reveals that tradeable permits created an incentive to search for "greener" production technologies as part of the compliance with the new market-based regulation. In particular, the resulting improvements to the existing power generation technologies surpass the increases in production costs. Therefore, the CAAA resulted in a net improvement in production efficiency of the U.S. electric utilities. This evidence is consistent with the latest findings of the literature, and supports the Porter hypothesis, that environmental regulation confers to firms a dynamic incentive to innovate.

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ACRONYMS

CAAA	:	U.S. Clean Air Amendments of 1990
CEPA	:	Canadian Environmental Protection Act
DEA	:	Data Envelopment Analysis
EPA	:	U.S. Environmental Protection Agency
IPCC	:	Inter Governmental Panel on Climate Change
MBIs	:	Market-Based Instruments
NAFTA	:	North American Free Trade Agreement

INTRODUCTION 1

"By wisdom a house is built,
And by understanding it is established;
And by knowledge the rooms are filled
With all precious and pleasant riches."

Proverbs 24:3-4

JEL Classification: L51; Q28; C51; D21; C44

1.1 Background

The last two decades of the twentieth century marked a gradual shift in environmental policy towards the use of economic instruments, particularly tradeable permit systems, for achieving environmental goals. [1] The long tradition of using conventional methods such as command and control regulation was gradually coming to an end, as more and more public policy makers were becoming aware of the resource costs of such regulation in terms of delivering certain environmental goals.

A tradeable permit system is an incentive-based policy tool that is designed to achieve specific environmental targets at a minimum cost. These targets are *caps* (limits) on sources of various pollutants. The incentives are created through emissions trading in order to reach the desirable levels of emissions. The caps specify quantity targets, which are achieved through permits being issued to the pollution sources. The number of permits being issued corresponds to the desired levels of aggregate emissions, which is typically a fraction of the emissions which would result in the absence of regulation. This scarcity value creates the incentive for permits trading.

[1] See Tietenberg (1985, 1997), OECD (1989), Huber *et al.* (1998), Carlson *et al.* (1998), Svendsen (1998), and Schmalensee *et al.* (1998).

The sources acquiring permits have the freedom to use or sell any excess of their endowment, depending on the extent to which they can reduce their emissions. For instance, if a source were able to achieve a lower level of emissions than specified by the regulator, then the excess of permits could be sold in the emissions market, or they could be banked for future use, and vice versa. Moreover, the tradeable permits create the flexibility for pollution sources to seek out the least-cost alternative for compliance. Some of the options available to pollution sources include investing in abatement capital equipment, improving existing technology, adopting new "green" technologies, fuel-switching, and adjusting the level of output.

The increasing awareness of the merits of the tradeable permits among policy makers, and those in political circles, reached a climax when the U. S. government unveiled the Clean Air Act Amendments in 1990 (CAAA). The CAAA provided legal provisions for the establishment of an emissions market in order to reduce sulfur dioxide (SO_2) emissions, which are a major precursor to acid rain, generated by the country's coal-fired electric utilities. [2] These provisions are considered a significant breakthrough in the scale of the economic instruments which can be used for environmental protection. [3] The Environmental Protection Agency (EPA), the national agency overseeing environmental regulation in the United States, was entrusted with the task of establishing the SO_2 emissions trading program, as authorized by the provisions.

The primary target of the CAAA was the U.S. electric power industry, whose hundreds of coal-fueled utilities were responsible for large masses of air pollutants. In 1997, these utilities accounted for 57% of the nation's production of electricity, while contributing about 70% of the SO_2, 30% of the NO_x, and 35% of the CO_2 of the total emissions from all sources of air pollution. [4] The proposed CAAA regulation called for

[2] A brief overview of the U.S. Clean Air Act Amendments of 1990, along with the details of the U.S. coal markets is provided, in Appendix II.

[3] For example, see Bohi and Burtraw, 1992.

[4] Annual Report, Energy Information Administration (1997) (http://www.eia.doe.gov).

each utility to adhere to a pre-specified limit of emissions. Any emissions beyond this limit required the utility to purchase additional permits, or to abate the SO_2 emissions by other means. [5] With the establishment of the SO_2 program in 1995, a market for the exchange of SO_2 credits was created. This program was launched in two Phases. Phase I, which was completed in 1999, was able to bring about millions of dollars in cost savings, [6] and created a strong rationale for the implementation of Phase II, which was started in January, 2000.

When the CAAA were enacted, many observers viewed them as an experiment in searching for a cost-effective means to remedy environmental problems. Now that Phase I has been completed, analysts are trying to ascertain the effectiveness of the experiment. Critics argue that the CAAA have increased the cost of power generation, and that they caused a productivity decline in the electric utility industry. Their arguments are largely based on comparisons between the observed fluctuations in growth rates of the electric utility sector and the energy sector, and those of the GDP growth rates. Furthermore, it has been argued [7] that the new measures are more restrictive than necessary, and that they have adversely affected the U.S. electric utility industry. [8]

Others maintain that the CAAA have indeed been a cost-effective measure in achieving environmental objectives because utilities responded with over-compliance and adopted new *green* technologies for power generation. These arguments are largely based on the statistics published by the Environmental Protection Agency (EPA) concerning the recorded cost savings in monitoring during Phase I, and the lower than the required aggregate emission levels achieved by the utilities. [9] Furthermore, following the passage of the CAAA, a substantial restructuring has occurred in power-generating plants. This was due to the fact that the affected utilities were attempting to accommodate the new

[5] Presently, one permit entitles the holder to one ton of SO_2 emissions in vintage year or any year later.
[6] See Schmalensee *et al.* (1998), Burtraw (1999), Ellerman *et al.* (2000) and Stavins (2000).
[7] For a critique of the market-based environmental regulation by a non-economist, see Beder (1994).
[8] See, for example, Yaisawarng and Klien (1994).
[9] Visit http://www.epa.gov for details.

environmental measures through various means of compliance. The latest findings reveal that such restructuring has come about at a social cost, but that the long-term social benefits will be substantial (Carlson *et al.*, 1998). For their part, activists representing influential environmental lobby groups, such as the Environmental Defense Fund and the Sierra Club, have agreed that the CAAA were indeed an essential move on the part of the U. S. government.

Because of these diverse opinions among researchers and stakeholders, it would be extremely difficult to determine the desirability of tradeable permits without a proper account of all potential costs and benefits of the CAAA. Moreover, a theoretical and empirical justification is essential to determine how policy priorities should be set between seemingly diverse strands of policies such as energy policy and environmental policy, in order to achieve the potential future benefits which would result from moving to market-based policies. Many economists would agree that there is a likely short-run trade-off between the two policies, namely environmental policy and energy policy. But a clear-cut answer will be possible only if an adequate theoretical and empirical justification could be provided for the performance of market-based policies. What is also necessary is a certain degree of co-ordination and co-operation between the two policies.

1.2 Motivation

As advocates of the CAAA, economists have a special role to play in addressing these important issues. Moreover, the task for the economist is to defend the desirability of market-based instruments, and to ensure that these instruments constitute a viable alternative to command and control regulation. Such a task will require ascertaining the economic costs of the CAAA, and to weigh them against the resulting benefits, so that the net social benefit or the net cost could be known prior to passing any judgment on the merits of the CAAA. However, the inadequate attention paid by the literature to the political economy considerations of market-based policies, i.e., political and institutional factors affecting the feasibility of tradeable permits, constrains the ability to undertake a meaningful evaluation of these policies. This is particularly true in the case of emissions trading programs, where a great many views exist among researchers and stakeholders on the performance of such programs, based on casual observations, which lacked theoretical or empirical underpinnings.

This dissertation will advance a rational basis for evaluating the economic performance of the market-based policies, with an emphasis on tradeable permits programs. In particular, an analytical framework is developed within the realm of the *positive* political economy principles to enable such an evaluation. To better focus on the fundamentals of emissions trading programs, this study will concentrate on the overall economic impact of the CAAA (i.e., the SO_2 emissions trading program) on the electric utility industry in the United States. The objectives are two-fold. Firstly, it will help determine the credibility of diverse views through quantitative analysis based on economic theory. Secondly, it will try to determine the desirability of tradeable permits systems in terms of *three* criteria, namely the *political economy factors*, *cost effectiveness* and *dynamic efficiency gains*, all of which are central to the evaluation of the actual performance of market-based policies.

This study recognizes the significance of political economy factors in the realization of cost savings and efficiency gains. Hence, the three criteria together form the basis for the analytical framework. The political factors are critical, because such factors alone would determine the ultimate feasibility of any public policy. Linked to this feasibility are a variety of other factors [10] which also affect the passage of regulation, from the origin to implementation, and then to the realization of environmental goals. Of these factors, two stand out: *cost effectiveness* and dynamic *efficiency gains*.

[10] A detailed discussion of these factors is presented in Section 2.5 of Chapter 2.

Perhaps the most influential factor driving the choice of environmental policies, particularly in the short-run, is the cost effectiveness, a criterion not found in the command and control type regulation. Simply put, the term 'cost effectiveness' refers to the minimum cost required to implement policies and to monitor their performance. On the other hand, long term survival of any environmental policy will depend on its ability to create incentives among firms to organize their production more efficiently. For example, in the context of this study, an efficient production is one that not only uses inputs optimally, but also creates an incentive for firms to seek new environmentally-friendly technologies. In this regard, 'efficiency gains' emerge as a salient feature that ensures the long-term survival of market-based policies.

The term 'efficiency' refers to the productivity gains resulting from lowering the per-unit-cost of power generation. These gains could also occur due to improvements in the existing technology, or from the use of new technologies and/or from the efficient allocation of inputs. All of these are potential positive secondary effects of the CAAA. The measures of efficiency thus bear a particular significance for any formal study which examines the actual impact of the CAAA on electric utilities. In other words, if production efficiency has been affected adversely, then the cost savings of the CAAA, resulting from the lower cost of enforcement and fewer emissions, have to be discounted against the loss in efficiency. On the other hand, if the CAAA have led to a higher level of efficiency in the power generation technology (apart from the other benefits), then such efficiency gains should be included in the economic evaluation of the CAAA. In either case, efficiency gains should be accounted for prior to assessing the overall effectiveness of the CAAA.

As a corollary, the study will provide an opportunity to test the significance of the highly debated *Porter hypothesis*, which claims that stringent environmental regulations, such as the CAAA, can actually work in favour of industries, as they provide the incentive for firms to seek out new technologies as a means of compliance. This study will determine whether the firms' incentive to adopt "green" technologies has been enhanced by emissions trading. In particular, it will examine whether the flexibility offered to firms by the tradeable permits programs to choose from a wide array of compliance options has had any impact on the adaptation of these new technologies.

1.3 Layout of the Dissertation

This dissertation presents a positive political economy framework for evaluating the performance of market-based environmental policies. The proposed analytical framework will examine the potential implications of market-based environmental regulation on the cost of production, on the productivity of capital, and on technology. With a focus on the U.S. SO_2 emissions trading program, the dissertation is organized as a combination of three *stand-alone* papers.

Following this introduction, the *first* paper (**Chapter 2**) presents a political economy framework, providing a basis for undertaking a meaningful evaluation of the market-based environmental policies. The underlying premise of this framework is its consideration of *actual* political, social, and market factors within the realm of positive economic theory. It focuses on the U.S. experience for two reasons. First, the United States is the world leader in using tradeable permit programs to attenuate environmental problems. Second, examining the experience of Canada's southern neighbour will help inform the policy debate currently unfolding in this country on the merits of tradeable permit programs.

The *second* paper (**Chapter 3**) is centered on the cost considerations of the market-based policies, with an emphasis on the SO_2 program. Using a panel data set [11] from the U.S. Federal Energy Regulatory Commission, a generalized cost function approach is adopted to estimate cost share equations, and to analyze the effects of the tradeable permit programs on the cost of power generation in the United States. In particular, the focus is on the firms' cost-minimization problem, and on the technological innovations induced by the SO_2 emissions trading program.

The *third* paper (**Chapter 4**) extends the analysis by adopting an approach based on the principles of operational research and econometrics, to further investigate the impact of the tradeable permit programs on production efficiency and technology. The investigation proceeds in two stages. In the first stage, the Data Envelopment Analysis (DEA) is used to explore the impact of the tradeable permit programs on the efficiency of the firms. [12] In the second stage, a random effects Tobit model is constructed to examine whether the DEA efficiency scores are affected by the firm-specific characteristics. This procedure enables an investigation of the consistency, and of the robustness of the econometric model of Chapter 3.

The last chapter (Chapter 5) presents a short discussion of the key findings from the analyses of the *three* papers. It will provide guidance as to how the evaluation of market-based policies should be undertaken, by drawing from the CAAA experience with the electric utilities of the United States. Some concluding comments, and suggestions for further research will also be offered.

[11] See Appendix I for details of this data set and the other series used in empirical analyses.
[12] Data Envelopment Analysis (DEA) is a useful non-parametric, linear programming method which has the potential for investigating efficiency aspects of regulation.

ENVIRONMENTAL PROTECTION, ECONOMIC INSTRUMENTS AND PUBLIC POLICY: A POLITICAL ECONOMY APPROACH TO TRADEABLE PERMITS

2

"No matter what policy instrument is chosen, it is necessary to identify the environmental goal of that policy."

D. Fullerton and R. N. Stavins
Resources for the Future, 1998

JEL Classification: Q28; L51; L94

2.1 Introduction

Economic theory suggests that the definition and allocation of property rights have considerable implications for market performance. If property rights are not well-defined, the underlying resource will be prone to the '*tragedy of the commons*' problem [1] where users of the resource do not fully internalize the costs of resource utilization. The result is that a resource is *overused* relative to what might have occurred had its complete ownership been assigned to an economic agent. [2] Its rent is dissipated in full or in part while under complete ownership it accrues to the owner entirely.

Most environmental problems have been analyzed in terms of the *open-access* framework. The key insight from the open-access literature is that any public policy aiming to address environmental concerns will operate more effectively within a well-defined system of property rights (Dales, 1968). Since markets do not exist for most of the environmental 'commodities' (e.g., air, water, ecosystems) because property rights are not well-defined, price signals cannot be used to allocate resources efficiently. An efficient allocation of

[1] This argument was first made by Gordon (1954) and discussed by Scott (1955). The term '*tragedy of the commons*' was coined by Hardin (1968).
[2] '*Economic agent*' may include an individual, business venture, government or a community.

resources under open access thus requires that public policies be devised to reinstate 'missing markets' so that the price mechanism will function effectively (Ledyard, 1987).

An immediate implication of this argument is that environmental problems can be successfully dealt with by designing policies to establish property rights (Coase 1960, Bromley, 1991). In general, systems of property rights can be characterized by *four* main features, namely *exclusivity*, *transferability*, *flexibility* and *enforceability*. Exclusivity ensures that all benefits and costs accruing to the ownership of a resource should accrue to the owner himself while transferability guarantees that the property rights established are transferable from one owner to another through voluntary exchange. Flexibility offers the adaptability to changes in decisions of the owner, by providing the ability in transforming the 'right' into money. Enforceability, on the other hand, assures the owner's ability to exercise his rights to prevent others from using the resource. In the context of the U.S. Clean Air Act Amendments of 1990 (hereafter, the **CAAA**), enforceability further ensures the ability to compensate the proprietor for the loss of her asset. If a property rights scheme is charaterized by these features it may be considered as well-defined and as we will see, can be used to find effective solutions to environmental problems.

A logical way to define property rights is through market-based instruments (MBIs). These instruments use market signals, i.e., prices, to influence the behavior of economic agents in a manner that is consistent with environmental objectives. In general, MBIs can be classified into two broad categories, namely *price instruments* and *quantity instruments*. Price instruments are intended to make environmental goods scarce or, alternatively, environmental '*bads*' costly for economic agents, either by altering the price of the environmental commodity or the market prices of the products which entail such 'bads'. A frequently used price instrument is emissions taxes, an instrument which dates back to Pigou (1920). For example, an effluent tax can be used to increase the cost of pulp and paper production by taxing factory discharges or by charging a price for clean water used. The goal is to encourage firms to cut down discharges and thereby, reduce water contamination.

Quantity instruments are used to enforce limits (or caps) on the quantity of environmental 'bads' or quality standards, and allow economic agents to find cost-effective ways to comply with these limits or standards. Emissions trading is now considered a dominant quantity instrument, which has gained recognition in recent years as a cost-effective economic instrument to overcome environmental problems. Unlike price instruments such as emissions taxes, which offer no assurance of the extent to which an 'undesirable activity' (or the environmental bad) can be reduced by taxing the source of that activity, quantity instruments, particularly emissions trading, offer the certainty of achieving certain reduction targets in such activities through market forces. This feature of emissions trading has been useful in drawing the attention of policy makers to this instrument, and in promoting its use for a wide array of environmental problems. [3] We will discuss the major applications of this instrument in Section 2.3.

The recognition of the role of economic instruments in environmental issues reached a climax with the passage of the CAAA. This regulation, in addition to providing statutory provisions for reducing the country's SO_2 emissions from coal-fired electric utilities, authorized, for the first time in the history of U.S. environmental regulation, the establishment of a market for trading SO_2 emissions rights throughout the United States. The CAAA which many economists consider now as a major breakthrough in the use of economic instruments for environmental problems were implemented in two Phases, namely Phase I (1990-1999) and Phase II (2000 onwards). Phase I achieved substantial cost savings amounting to hundreds of millions of dollars (Ellerman *et al.*, 2000), most of which are attributable to the lower resource cost associated with tradeable permit programs, as compared to command and control type policies (Mclean, 1997). Economists predict that Phase II, which began in January, 2000, will perform similarly or better, despite the tighter cap on SO_2 emissions (Ellerman *et al.*, 2000, Burtraw, 1999).

[3] See Farrell (1991), Carlson *et al.* (1998) and Schmalensee *et al.* (1998).

A considerable literature now exists which examines various facets of tradeable permits programs, particularly the SO_2 program. This literature is built on the insights of early economists such as Pigou (1920), Coase (1960), Dales (1968), and Montgomery (1972) who recognized the importance of creating *missing* property rights in order to correct the underlying environmental externalities. Nevertheless, a dichotomy exists in terms of the approaches taken by economists. One branch of the literature attempts to evaluate the performance of market-based environmental policies solely on the basis of cost effectiveness or/and productivity gains. [4] A major performance criterion used by these authors is costs/benefits comparison between different policies.

Another branch, which is of relatively recent origin, is primarily concerned with actual market and political conditions under which environmental policies are implemented. For example, it has been suggested that the evaluation of environmental policy should take into account the pre-existing market distortions (e.g., taxes, entry barriers) along with the resulting institutional and equity issues (e.g., political feasibility, welfare effects). [5] Going a step further, some economists have tried to analyze the achievements of the SO_2 program from a political economy perspective (e.g., Keohane *et al.*, 1998).

Despite the significance of the pure economic criteria such as the cost effectiveness and the efficiency gains (the focus of the former branch) in evaluations of public policies, the role of political and institutional factors (the focus of the latter branch) is equally important in accounting for the strengths and drawbacks of market-based policies under varying political/economic conditions. As Coase (1992) noted in his Nobel Lecture that the profession should pay special attention to the existing institutional structure in evaluations of the true costs of participating in markets. The implication is that a meaningful evaluation of market-based policies, particularly tradeable permits programs, will

[4] See, for example, Crampton (2000), Burtraw (1999), Carlson *et al.* (1998), Schmalensee *et al.*(1998), Rico (1995), and Yaisawarng and Klein (1994).
[5] See, in particular, Goulder *et al.*(1997), Joskow, *et al.* (1998), Goulder and Parry (1999), and Pizer (1997).

simultaneously consider economic criteria and the institutional and political economy factors before passing judgement on the performance of public policies. It seems timely, therefore, to assemble economic tools to facilitate the evaluation of environmental policies.

In this chapter, we will develop a political economy *analytical framework* which will offer a synthesis of these seemingly diverse strands of literature on environmental policy analysis. This framework will introduce an array of essential criteria to define and articulate a meaningful evaluation of the U.S. SO_2 program, both in terms of 'achieved' and 'achievable' goals. The objective is to combine all important elements. The criteria which will form the basis for our inquiry into *all* important institutional dimensions of emissions trading programs, will include issues of economic efficiency, cost savings, design and implementation, initial allocation and life-span of permits, caps and standards, equity, property rights characteristics, institutional structure, interest groups, transaction costs, production technologies, product market characteristics, market imperfections, price vs. quantity debate, hybrid of economic instruments (e.g., *safety valve*), revenue recycling, and 'hot spots'. We will also examine the secondary effects of the SO_2 program including the impacts on GDP and energy markets, geographical characteristics of emissions reductions, interregional and firm level trading of emissions permits.

One important objective of this chapter is to set the stage for the empirical analyses in Chapters 3 and 4 of the dissertation. These two chapters use a data set [6] covering sixty-eight of the largest electric utilities from the United States, and undertake a methodological inquiry into the U.S. experience with the use of tradeable permits programs. While our approach is based on a narrower, strictly economic viewpoint, that focuses on the U.S. SO_2 emissions trading program, the goal of this chapter is to acquire a broader understanding of all dimensions of emissions trading, and to reflect on the need for the methodological evaluation in chapters 3 and 4. Using the *proposed analytical framework* we will examine

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[6] Details of the data series used along with the sources are provided in Appendix I.

the significance of the political dimensions of market-based environmental policies. While it is easy to recognize the importance of each of these dimensions, two criteria in particular appear to be critical for the *choice* of market-based instruments in environmental policy. The two criteria, namely the *cost effectiveness* and *efficiency gains*, as we will see, are the fundamental determinants of political support for the instrument choice in democratic settings. Hence, this dissertation will further its empirical investigation into the costs and efficiency aspects of emissions trading programs. More specifically, Chapter 3 will analyze the *cost aspects* of this program using an econometric framework, and Chapter 4 will extend the analysis to account for the *efficiency aspects* using the Data Envelopment Analysis. [7]

The remainder of this paper is organized as follows. Following this introduction, Section 2.2 presents the political economy characteristics of market-based instruments. Section 2.3 will consider the scope of market-based instruments in the context of environmental objectives. Section 2.4 will focus on emissions trading, and explore its merits (and potential drawbacks) as compared to other market-based instruments. Section 2.5 will present the 'analytical framework', outlining the essential criteria for evaluation of emission trading programs. Section 2.6 is devoted to the highlights of major emission trading programs in North America. Section 2.7 will provide a detailed discussion of the U.S. SO_2 emissions trading program, along with the statistics pertaining to Phase I and Phase II. Section 2.8 will present a tabular summary of the analytical framework developed in Section 2.5, using the SO_2 program as an example. Section 2.9 will review Canada's limited experience with market-based instruments, and discuss the lessons to be learned from the experience of the United States. Finally, Section 2.10 puts all of the findings in context to provide motivation for the empirical analysis of *cost* and *efficiency* aspects of emissions trading in Chapters 3 and 4 of the dissertation respectively.

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[7] Data Envelopment Analysis (DEA) is a linear programming method used to explore efficiency aspects of production activities.

2.2 Political Economy of Market-Based Instruments

It is essential to distinguish between the two major strands of modern economic theory, namely *positive economics* and *normative economics*. The former is based on the facts and logical deductions (i.e., verifiable hypotheses) that can be tested by analytical means. The latter, on the other hand, is based on value judgements, and is often "prescription" and/or policy-oriented. In other words, this dichotomy is best viewed by considering positive economics as having to do with "what is" and normative economics as having to do with "what ought to be" (Friedman, 1953).

The exposition of this Chapter is primarily based on the realms of positive economics and we will allude to the facts and empirical evidence to advance our dialogue on market-based instruments. In particular, in the proposed analytical framework (see Figure 2.2) environmental policy formulation is portrayed as having *three* stages, namely *policy target*, *instrument choice*, and *performance appraisal*. Of the three stages, the 'instrument choice' is regarded as the equilibrium outcome of a 'political market', as perceived by Keohane, *et al.* (1998), and Boyer and Laffont (1999), where demand and supply conditions are the driving forces of environmental regulation. As outlined in Figure 2.2 on page 27 (and as will be discussed in Section 2.5.2), we have identified critical factors of this "political market", and consider their roles in arriving at the equilibrium outcome.

The economic arguments prescribing the use of market-based instruments for environmental protection date back to 1960s. Early economists including Coase (1960), Dales (1968) and Montgomery (1972) were among those who first emphasized the inefficiencies of the command and control type policies, and the important role of the market in allocating scarce environmental resources. Favouring the use of market-based environmental policies, they showed how economic instruments, particularly tradeable permits systems, can effectively be used to attain certain environmental goals. To many economists' surprise, however, these economic arguments did not make their way through to public policy circles for many years until the U.S. government provided for a legal mandate for the implementation of tradeable permits systems through the CAAA.

The casual explanation that the uncertainty due to the lack of real world experience with tradeable permits has constrained their early implementation by the legislature has failed to convince many economists. Instead, economists were eager to find more intelligible explanations for prolonged time period of roughly 30 years between the propagation of tradeable permits and their large scale applications in environmental policy. This search for compelling evidence led to a large body of literature, which attempted to explain the hiatus from a political economy perspective (see for example, Keohane, *et al.*, 1998, and Stavins, 2000). Because the goal of this chapter is to facilitate a meaningful evaluation of the tradeable permits systems, the knowledge of the political economy dimensions in environmental policy will be a substantial *value-added* to the development of our proposed analytical framework.

The literature focussing on the political economy aspects starts by examining 'rent-seeking' behaviour of both firms (or sources) and regulators. For example, the preference of firms for environmental standards, a major command and control (CAC) method, emerges when enforceable 'barriers to entry' are accompanied by the standards, because standards produce 'economic rents' to the incumbent firms. On the contrary, market-based instruments (MBIs), particularly taxes and tradeable permits distributed through auctions, will require firms to pay for abatement as well as pollution costs for the portion of emissions not abated.

The green activists prefer environmental standards since they are easy to communicate to their audience (Hahn, 1989). One important political economy dimension would help explain the efforts of the state regulators and legislators to accommodate the concerns of green activists who often view tradeable permits as 'licenses to pollute'. Contrary to the view in the economic literature that tradeable permits are a way of creating 'missing property rights' (Coase, 1960, Dales, 1968, Ledyard, 1987), the CAAA defines these permits as "limited authorizations to emit", and distanced itself from recognizing them as 'property rights' This seemingly unwarranted interpretation of tradeable permits has been viewed by economists as a concession offered to certain environmental lobby groups who resist the categorization of air mass as private property (Tietenberg, 1998). Furthermore, it has been argued that the CAAA definition of property rights deemed essential to prevent the state from compensating sources for loss of 'rights' when it decides that the permits be ratcheted down or the durability of their life be reduced. In these cases, the 'eminent domain' does not apply since there is no need for compensation.

On another front, the regulators, mainly public policy makers and elected officials, prefer the CACs because these officials could benefit from the long experience they possess in dealing with the CACs. This administrative know-how helps them 'establish' themselves among constituents more easily than the 'little-known' market-based policies, for which industries have offered little support historically. This latter reason plays a critical role in political decisions since the CACs, as compared to the MBIs, typically prevent the public from noticing the underlying costs of standards to sources (and to economy) while the benefits can easily be propagated to voters, as documented evidence can be provided along with the supporting technical directives. The legislator support for the CACs, on the other hand, arises mainly because they provide a greater degree of control for legislators, as compared to MBIs, over distributional impacts of environmental regulation (Romer and Rosenthal, 1987, and Keohane, *et al.*, 1998). Since equity issues are a major determinant of political support for public policies, obviously, policies with lower distributional impacts become better candidates for environmental policy choice.

Historically, the CACs have constrained new sources from entering markets through 'barriers to entry' whenever standards have been implemented. This is in part to protect the incumbent sources from competition. These barriers, for example, by limiting entry, impose additional costs on new firms, or alternatively subsidies for the regulated industry (Rasmusen and Zupin, 1991). However, in the case of green activists, these barriers are attractive because they view such barriers as effectively preventing future emissions from increasing. For legislators, the barriers provide opportunities to protect the interests of incumbent groups from industry. On the contrary, MBIs, particularly tradeable permits do not offer these 'privileges' to the respective groups.

Moreover, when the tradeable permits systems have been adopted, the dominant method of allocating initial permits had been grandfathering. Contrasting with auctions, the preference for *gratis* allocation of permits could be explained within the realms of 'rent-seeking' behaviour. As noted, tradeable permits, if distributed freely (as opposed to auctioning them or imposing pollution taxes), will distribute rents to the incumbent firms, which will become an 'implicit' barrier to entry since newcomers are not entitled to receive permits. For legislators, granfathering provides a better handle on distributional effects of the trading system, since the concerns for revenue transfers in the case of auctions do not arise in this case (see Goulder *et al.*, 1999, Rasmusen and Zupan, 1991, and Keohane, *et al.*, 1998).

Despite these inherent preferences towards the CACs, MBIs in recent years, particularly emissions trading programs, appear to have picked up lot of ground in public policy circles, and in some cases, have come so far to circumvent the long-drawn tradition of the CAC-based environmental regulation. Possible explanations for this new impetus for emissions trading programs may include increasing understanding of their attractive properties, enormously increasing pollution cost burdens on governments, and shifts in political ideologies towards market based solutions, at least in the United States (Keohane, *et al.*, 1998 and Tietenberg, 1988). With this knowledge of the political economy dimensions of market-based environmental policies, we now turn to examine the potential of the market-based instruments for the protection of the environment.

2.3 Market-Based Instruments and the Environment

A fundamental objective of any environmental policy is to reduce environmental degradation with the lowest possible *social* cost. One way to achieve this objective is to align private costs with social costs, an idea that dates back to Pigou (1920), who argued that social welfare could be enhanced if resources were diverted to sectors where private costs and benefits were as much as their social counterparts (assuming that markets are perfect). The implication is that, by placing a 'value' on an open-access resource (for example, by constraining open access through taxing) one could attract those users who 'value' the resource most, while keeping others away. The implication is that it is possible to internalize environmental *externalities* into the decision making of the relevant parties. Market-based instruments are an important means to internalize externalities. These instruments influence the behaviour of economic agents through *market signals* rather than through explicit instructions directing environmental goals and methods of compliance. Market-based policies are sometimes described as "harnessing market forces" because of the *incentive* inherent in these policies to encourage firms to take actions to achieve environmental goals in a way that serve these firms' interests, and that are consistent with policy objectives (Stavins, 2000).

The use of market-based environmental policies has long been favoured by economists. [8] The underlying argument is that these policies, unlike *command and control* type regulations, incorporate environmental concerns directly into the price mechanism, leading potentially to efficient market solutions. Market-based policies also trigger actions by firms and consumers that help achieve given environmental goals in a cost-effective manner. Until recently, policy makers largely ignored these economic arguments favouring

[8] See, for example, Tietenberg (1985), Baumol & Oates (1988), Field and Olewiler (1995), McLean (1996), Blackman & Harrington (1999), and Burtraw (1999).

market-based policies. Instead, they extensively relied on other instruments such as technological standards and effluent charges to deal with environmental problems.

However, this perception began to change after the realization that these other instruments were becoming increasingly ineffective and unattractive on various accounts, namely high administration costs, inability to meet specific environmental targets, and changing political climate (Keohane, *et al*, 1998). For the purpose of this Chapter, all such policy alternative instruments are classified into one broad category, namely *command and control* methods (e.g., technological standards). We classify all other policy instruments belonging to the family of market-based policies as *incentive-based* strategies. These incentive-based (or market-based) strategies are further divided into two groups, namely *price* instruments (or price-based approaches) and *quantity* instruments (or quantity-based approaches). A fundamental difference between the two lies in the approach taken by each instrument to achieve environmental goals.

The *price-based* approaches dictate that the creation of a market price is essential to signal scarcity value of environmental resources and that it will help optimally adjust the consumption of such resources by economic agents. Among popular price-based approaches are environmental charges and pollution taxes. Environmental charges assign 'prices' for the use of environmental resources. The idea is to accede to the 'polluter pays' principle, i.e., to force the polluter to pay for the use or the damage of the resource. These charges reflect the cost to society for the use of *open access* resources, and they promote resource conservation to the extent that the users are given an economic incentive to control their consumption of the scarce environmental factor. Emissions taxes are another widely used price-based instrument to deal with environmental externalities. These taxes target the environmental problem at its source, and create a *value* (or a price) on the underlying resource being overused or polluted. When all sources of pollution are subject to the same indirect tax, sources will adjust their actions so that the equimarginal rule [9] is satisfied. Interestingly, policy makers do not have to know abatement parameters for this to occur; it is sufficient that economic agents be faced with the tax and make their own adjustments, exactly in the same way that the price system allows decentralization of decisions by economic agents.

The *quantity-based* approaches recognize the absence or lack of property rights for environmental resources as the fundamental reason for the existence of environmental problems (see, for example, Ostrom and Schlager, 1996). Thus the remedy is to establish property rights and to allow economic agents to trade these rights to achieve the environmental goals. A powerful instrument emerging from this approach is the *tradeable permits systems*. These systems are a means of assigning rights to (or titles for) an environmental resource, and allowing economic agents to trade these rights, so that a price reflecting the scarcity of environmental resource is created through the emissions market. After determining the desired level (or the quantity target or the cap) of environmental quality by the policy maker, a certain number of permits corresponding to the policy target are issued. The interactions of economic agents in permits market are then used as a vehicle to achieve the overall environmental goal at the least possible cost. This substantially reduces the regulatory burden, as it minimizes the costs of monitoring compliance by the firms.

Tradeable permits are gathering momentum as a leading economic instrument among alternatives of environmental instruments, such as command and control methods, taxes, deposit systems, etc. The inefficiencies of these conventional methods, their inability to deliver anticipated environmental goals, and the enormous cost burdens borne by governments and tax payers are largely responsible for the increasing popularity of

[9] The equimarginal rule dictates that net benefits are maximized when the marginal benefits from an allocation equal the marginal costs and marginal costs for all sources are equalized (Tietenberg, 2000).

tradeable permits around the world. In recent years, there has been a growing interest among public policy makers to search for better policy tools to deal with a variety of environmental concerns. The understanding of the promising features of tradeable permits reached its peak with the passage of the CAAA in the United States. The main goal of the CAAA was to put a permissible limit (or a *cap*) on SO_2 emissions generated by coal-fuelled electric utilities in the United States. Nearly ten years after the passage of these CAAA, the latest evidence suggests that the program has been highly successful not only in achieving the set targets, but also in resulting in millions of dollars in cost savings for the U.S. tax payer. [10]

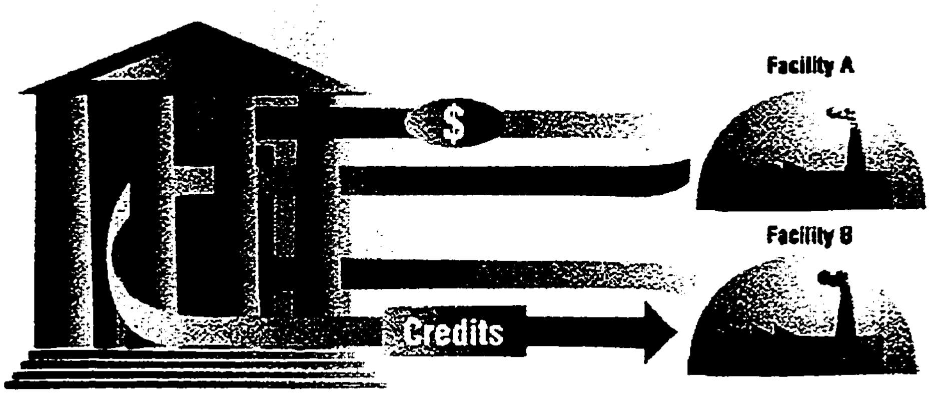

Figure 2.1: Emissions Trading in Practice

2.4 Economics of Emissions Trading

Emission trading programs are essentially characterized by *three* elements, namely a *cap*, *permits*, and a *market*. The *cap* approximates an environmental standard ideally determined through cost-benefit analysis, [11] and refers to the overall permissible limit of

[10] The SO_2 emissions trading program will be discussed in detail in Section 2.5.
[11] The equivalence of *cap* and *standard* will be discussed in detail in Section 2.4.2.1 below.

emissions allowed by the regulator, often for a specific geographical jurisdiction. [12] The *permits* (also called credits) establish rights to emit a pollutant, and entitle the emitter to a certain amount such as one ton of SO_2 for each permit. Thus, the ability to pollute is bound by the number of permits held by the emitter. The *market* facilitates the voluntary exchange of emissions rights (or credits) between emitters, as shown in Figure 2.1.

Since the level of emissions is fixed under the tradeable permits systems, and permits are scarce, incentives for permits trading are created among sources through the market. Emissions trading programs require policy targets to be set in terms of the quantity, and are achieved by allowing the trading of permits between firms. Since individual needs for permits vary across firms in line with their capacity and production technologies and costs, firms are induced to engage in permits trading. Firms which reduce their emissions below the level allowed by the regulator (or the standard set by the policy) are eligible to sell the extra permits to other firms or, in some cases, could *bank* [13] them for future use.

Transferability assures the free exchange of permits at prices determined by the market. Since the market price of permits is determined solely by the interaction between buyers and sellers in the market, it is reflective of marginal abatement cost of emissions across firms. Thus, firms whose marginal abatement costs are higher (lower) than the prevailing market price of permits have the incentive to buy (sell) permits to meet the regulatory targets. This implies a potential for the policy target (or the *cap*) to be achieved at the lowest possible cost. A major advantage of emissions trading, as compared to other price-based approaches such as emissions taxes, is that it does not require *a priori* knowledge of production technology to ensure firm compliance, whereas in the case of a tax, the knowledge of both demand and cost structures of the commodity is essential prior to imposing a tax.

[12] For example, under the Kyoto Protocol, Canada is committed to reduce its greenhouse gas emissions (GHG) by 6% from its 1990 emissions levels by the year 2010. If the ratification is achieved by an emissions trading program, the 6% reduction becomes the *cap* on GHG emissions within Canada.

[13] *Banking* involves storing (or hoarding) of permits by emitters for subsequent use or sale.

Nonetheless, a number of conditions appear to be critical for achieving economic efficiency through emissions trading. First of all, sources should differ substantially in terms of abatement costs. This is essential to create incentives for trading among sources. Second of all, transaction costs, e.g., brokerage, agency fees, information acquisition costs, etc. should be low in order realize gains from trade. If these costs are high, cost savings would be affected due to lack of incentives among sources to engage in trading. Third, sources must possess enough resources to undertake economic calculations, i.e., to compare marginal costs of emissions reduction through alternative methods such as buying permits, paying taxes or abatement. [14]

It seems that one of the challenges facing policy makers, those who embark on the use of economic instruments, is to ensure that the created property rights are fulfilling the criteria that are essential for achieving environmental goals through market-based policies. For economists, on the other hand, the challenge is to develop a set of criteria that can be used to evaluate all important dimensions of emissions trading programs. To this end, this study will develop an *analytical framework* within the realms of positive economic theory, synthesizing major economic and institutional arguments to facilitate an all-round performance appraisal of tradeable emissions permits programs. This framework may permit a better understanding than approaches which have focussed almost exclusively one side of the problem at a time.

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[14] Emission trading appears to be better suited for *point sources* and *uniformly mixed* pollutants than others. Point sources are those discharging effluent through a readily identifiable or fixed location. Municipal sources are an example where the quantity of discharges can be easily monitored and local effects such as effects on ambient air quality can be accounted for. Thus, a regional permit program is useful to deal with the problem (compare this with non-point sources such as automobiles). Uniformly mixed pollutants are those that are absorbed by the atmosphere evenly regardless of the location of sources (for example, greenhouse gases/ozone). In such cases, emissions permits can be issued in line with the rate of emissions flow per unit of time. See Psekin (1986).

2.5 Analytical Framework for Evaluation of Tradeable Permits Programs

It is timely that we develop an analytical framework [15] to calibrate all essential criteria to facilitate an overall evaluation of market-based policies. The framework we advance will involve a *three-stage* evaluation process where essential criteria are grouped under each of the stages. Later on, in Section 2.6 this framework will be used to evaluate the performance of the U.S. SO_2 program. To guide us in the remainder of the discussion, we have presented in Figure 2.2 a schematic representation of the proposed analytical framework, highlighting its key components governing the proposed evaluation. For easy exposition, we have linked up all the elements of the *three stages* to portray the linkages involved in the tradeable permits systems. The three stages are referred to as *policy target*, *instrument choice* and *performance appraisal*.

The policy target depicts the stage where the parties involved in the regulatory process, along with other stakeholders, debate the stringency of the goal set by the policy. The views (and concerns) of these parties will eventually give rise to the second stage, namely the instrument choice. At this stage, a wide array of scenarios, as outlined in Figure 2.2, is considered. A consensus will then be reached between the parties, setting the stage for the implementation of a particular policy. For the purpose of the present study, we will consider 'emissions trading' as being the policy that various parties have agreed upon.

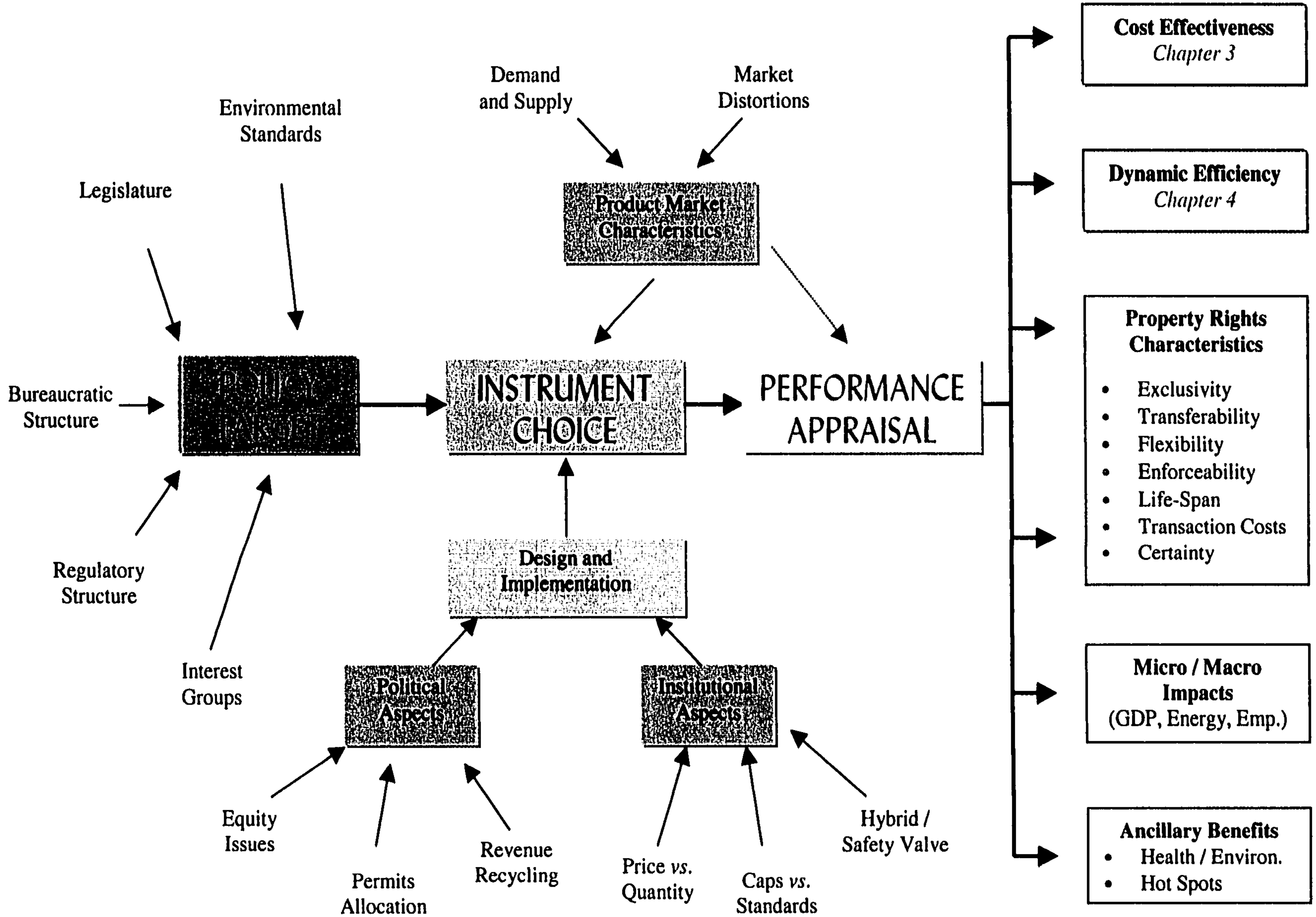
This analytical framework can readily be applied to evaluate any other public policies. The third stage, namely the performance appraisal, is the core of this analysis and thus, is

[15] It should be noted in advance that the proposed analytical framework will constitute *three* important stages involving the passage of market-based environmental policies in market economies. To capture the essence of actual market conditions, under which such policies are implemented, the framework is founded in the realm of positive theory of political economy. The goal is to facilitate a meaningful evaluation of emissions trading programs, by considering *all* potential political economy issues that influence the course of environmental policy formulation. As such, the proposed framework deviates from other standard frameworks used in decision sciences, which are often referred to as "utility analysis". For a most recent risk analysis decision framework in fisheries management, see Lane and Stephenson (1998).

important on three accounts. First, it is the critical stage where the implemented policy is 'validated' in terms of the achievements, which will determine the future survival of that policy. Second, it is the stage where a variety of opinions exist in the literature as to which criteria should be used to endorse a policy or the relative importance of different criteria from a performance appraisal point of view. Third and most importantly, it is the stage where the primary evaluation criteria will be chosen for further investigation in Chapters 3 and 4 of the dissertation. In other words, it is the stage where the proposed analytical framework attempts to harmonize all dimensions of the arguments to permit an overall evaluation of emissions trading programs. In what follows we will consider each of these stages in detail.

Figure 2.2

A Political Economy Framework
(Schematic View)



2.5.1 Policy Target

Public policy formulation in a democratic setting is influenced by numerous political and institutional factors (Tripp and Dudek, 1989). Several of these factors appear to be of particular significance for the initial stage where *policy targets* are determined. It is therefore important to explore these factors which will collectively determine the passage of the policy and the intensity of the target. In Figure 2.2, we have classified all major factors affecting the setting of policy targets, especially those involving environmental goals, into *four* broad components:

- **Institutional Structure**
    - Legislature
    - Bureaucracy
- **Regulatory Structure**
- **Environmental Standards / Practices**
- **Interest Groups**

Let's examine the role of these factors in the setting of environmental policy targets.

2.5.1.1 Institutional Structure

Legislature

Because the implementation of market-based instruments is superimposed on the *existing* institutional structure, the support of the legislature for the proposed policy targets becomes an interesting aspect of public policy formulation. In democracies, this support is often measured by a majority rule which involves a voting process to determine the level of desirability for the policy in question. In terms of economic theory, the legislative support can be viewed as the aggregate of individual support of lawmakers, which leads to the 'market equilibrium' (Keohane *et al.*, 1998), where markets will benefit from a legal system that facilitates ordered domains of exchange (Bromley, 1993). Hence, the aggregate support for a specific economic instrument will be the legislators' utility maximizing choice, which depends on two important factors, namely campaign contributions (lobby group interests) and voter preferences (avenue to secure power). In other words, legislators are confronted with a *demand* (i.e., voters and campaign contributions) and *supply* (i.e., policy instruments) decision, which eventually leads to the *market equilibrium* (i.e., the choice of instrument).

To the extent that the interests of these two groups (voters and lobbyists) overlap with each other, the legislators' utility maximization problem is trivial. Nonetheless, in reality, the difficult, but more interesting case occurs when such interests do not overlap. As noted, the interest groups often have their own agenda for which they seek to maximize legislature support through campaign contributions. The objectives of voters, on the other hand, are likely to be those shared by a majority of the public, which are of general interest and could benefit the society as a whole. For example, industry groups may want the legislators to protect their industries from foreign competition, an objective which is consistent with their profit maximizing behaviour. On the contrary, constituents may prefer a competitive market so that they can benefit from lower prices. In such circumstances, the aggregate support from the legislators for a particular policy will depend on the relative weights that they will assign to the seemingly diverse preferences in their utility maximization problem.

It should be noted, therefore, that, in cases where market-based instruments are being considered to pursue environmental objectives, the legislature will play an extremely important role in the "target setting" stage, and that this policy target will be a reflection of voter preferences, as well as lobby group interests. Moreover, the legislators at this stage of setting targets will have the final say as to whether a particular instrument (or policy) should be chosen in favour of its predecessors (such as command and control regulation) or other alternative candidates (such as taxes). Thus it is essential that the legislative support be considered as an important determinant of environmental policy at the 'target setting' stage, and be included in the evaluation of policy performance.

Bureaucracy

State bureaucracies also play an important role in the setting of public policy targets. As agents of the incumbent government and voters, the bureaucracy is meant to cater to the needs of the public by exercising actions which are economically sound, socially desirable and politically pursuable. An essential component of these actions involves setting goals or targets. Nonetheless, the bureaucracies are often constrained in their ability to pursue policy goals as a separate entity, because they need the cooperation or agreement of other players of the system, namely those within the legislative structure, the regulatory structure, and the interest groups to be discussed below.

For the purpose of our analytical framework, the importance of institutional structure at the stage of 'setting policy targets' comes from the government's ability to gain political support for policies under consideration. In other words, the government will act to reconcile views of interest groups by strengthening political support for the policy. In turn, this will increase the chances for the passage of policies. Because of their importance, it is essential, therefore, that the institutional factors discussed above also be part of the evaluation of public policies.

2.5.1.2 Regulatory Structure

On almost all occasions where market-based environmental policies were introduced to remedy environmental externalities, such policies have been implemented in imperfect market conditions or in the presence of pre-existing market distortions. The intensity of these distortions is a reflection of the existing regulatory structure (or regulatory culture). Most of market distortions results from the existence of some form of tax. Even though the primary motive for the imposition of taxes is to collect funds for financing public goods, environmental motives are the *raison d'être* of other taxes. Moreover, there are other imperfect conditions created through certain standards, which are often based on norms, beliefs, principles, or cultural values governing allocation of resources (Johnston, 1996).

Table 2.1

Comparison of U.S. and UK Regulatory Styles

United States	United Kingdom
Regulations are complex and rigid	Regulations are flexible and informal
Extensive use of uniform standards / increasing use of market instruments	Preference for individually negotiated, site specific standards
Suspicion of industry self regulation	Encouragement of industry self regulation
Courts used extensively	Courts used rarely
Minimal administrative discretion	Maximum administrative discretion
Relations between industry and regulator characterized by conflict	Relations between industry and regulator characterized by cooperation
Freedom of information	Confidentiality
High administrative costs	Low administrative costs
Regulation is focus of conflict	Regulation has low political profile

Source: Sorrell (1999), p.193.

Regardless of the nature, these distortions caused by the existing regulation are critical for the performance of market-based policies, particularly emissions trading programs. There have been instances where government efforts to implement market-based environmental policies have failed prematurely due to inadmissibility of such policies into the existing regulatory structure in product markets. A prominent example is the British government's initiative to implement emissions trading systems within the 'regulatory culture' prevailing in that country (Sorrell, 1999). As shown in Table 2.1 above, the UK regulatory structure, as compared to that of the United States, is seen as 'non-conducive' to market-based instruments, such as emissions trading programs.

In a path-breaking study completed recently, Goulder *et al.* (1999) have emphasized the need for serious consideration of the existing regulatory structure prior to the estimation of the benefits, mainly cost savings, accruing to market-based policies. Their finding of the 'hidden costs' in the magnitude of over a billion dollars, resulting from the existing market distortions due to taxes, has cast doubts even on the conservative estimates of cost savings from the U.S. SO_2 program, which have been undertaken without reference to the so called 'tax interaction effects'. It is thus clear why it is essential that regulatory characteristics should also be a part of the evaluation criteria of market-based policies.

2.5.1.3 Environmental Standards / Practices

The national standards protecting 'environmental quality', such as those governing ambient air quality and exploitation of natural resources, are relevant for implementation of market-based environmental policies. In fact, the *caps* representing quantitative targets of emissions trading programs can be interpreted as proxies to the scientific standards (or the norms), which are ideally determined through cost-benefit analysis. Since both caps and standards are set to achieve certain levels of environmental quality, the knowledge of the existing standards is useful for the policy maker on *three* accounts. First, it will ensure the compatibility of caps and the underlying standards. This will allow policy makers to portray the environmental policy as a means of complying with the standards. Second, the existing standards are useful as a guidance in setting the caps as part of the environmental policy. This helps communicate the anticipated policy goal or the cap as the same as the standards or the accepted norms. Third, following the implementation of the emissions trading program, the deviations from the cap can easily be interpreted as non-compliance with the standards, justifying the imposition of penalties for non-compliance.

One further observation concerning environmental standards involving the tightening of the cap over time is in order. The RECLAIM program, for example, has tightened its cap over a nine year period while the celebrated U.S. SO_2 program has introduced a narrower cap for Phase II which came into effect in January, 2000. As such, the amount of emissions rights (or permits) is set to decline over time. As emissions permits become relatively more scarce in this fashion, markets for emissions trading resemble markets for non-renewable resources because the portions of permits being withdrawn or retired over time are similar to those non-renewable resources that are exhausted due to usage. Hence, if caps are to be viewed as standards, then tradeable permits should be inherited with a time varying scarcity value. [16] Therefore, it appears that the evaluation of emissions trading programs would not be complete unless the linkages of the environmental standards and policy goals are established.

2.5.1.4 Interest Groups

Interest (or lobby) groups [17] are formed to pursue certain beliefs, values or objectives commonly shared by a group of individuals. In the public policy context, the pursuance of group interests often entails 'passing judgements' on various policy initiatives advanced by the government. This is because interest groups are eager to have their personal interests reflected in the final outcome of the policy to the maximum extent possible. On the one hand, these interests exist because the policy target--the environmental policy--is essentially a *public good*, and thus economic agents as individuals or as groups could draw

[16] This observation is consistent with arguments of Hotelling (1931), and Crabbé and Long (1993) who analyzed fish stocks.

[17] For the purpose of this discussion, interest groups are separated from government bureaucracies and legal institutions. The latter is discussed separately.

utility from its consumption. On another hand, these interests are sometimes seen as imposing 'implicit conditions' on public policies which are typically funded by taxpayer money. This latter motive arises from the group members' 'right' as taxpayers.

Regardless of the motive, these interactions of interest groups have significant bearing on public policy formulation. This is particularly true in the case of market-based tradeable permits systems, a policy that has simultaneously led to conflicting views among various interest groups. Groups pursuing environmental values, on many occasions, have considered market-based policies as vehicles for taking their individual goals forward, and therefore, they have been favourable to such policies. [18] Yet some other groups, particularly those representing the interests of industries, have opposed the same policies as being detrimental to free trade or industry competitiveness. Hence, the role of interest groups is critical at this initial stage of policy where goals are being set.

An ideal example is the U.S. SO_2 emissions trading program where the Environmental Defence (ED), a powerful lobby group based in Washington D.C., has pledged its full support for the proposed emissions trading systems, which were at the time under consideration by the Bush Administration as part of the CAAA. In fact, the ED's efforts appear to have propagated a powerful message on the effectiveness of tradeable permits on environmental grounds, making it politically feasible to achieve larger reductions in SO_2 emissions than would otherwise be possible (Keohane *et al.*, 1998).

Furthermore, economists who modelled the resource allocation decisions of competing interest groups, have asserted that policy 'outcomes' would depend on pressures exerted by interest groups (see Becker, 1983). Because the interest group interactions in public policy formulation demonstrate their potential for influencing the policy itself, particularly during the course of setting targets, interest (or lobby) groups are considered as another important component of our analytical framework.

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[18] However, there are other environmental groups those who view tradeable permits as "licenses to pollute" (see Kelman, 1981 for details).

2.5.2 Instrument Choice

Once the policy targets have been set, the process moves into a critical stage where a choice has to be made (and justified) over a wide array of alternative policies available, in order to achieve the target being pursued. As in the previous stage, numerous factors will influence the choice of policy instruments. For the purpose of this study, all of the factors are classified into *three* broad categories, namely *political aspects*, *institutional aspects*, and *product market characteristics*.

Figure 2.3

Design and Implementation

❖ **Political Aspects**

- Equity Issues
- Initial Allocation of
- Permits
- Revenue-Recycling

❖ **Institutional Aspects**

- Price vs. Quantity Instruments
- Emissions '*caps*' vs.
- '*standards*'
- Hybrid / 'safety valve'

❖ **Product Market Characteristics**

- Demand and Supply Characteristics
- Pre-Existing Market Distortions

As depicted in Figure 2.3, the issues of design and implementation are of particular significance for any market-based environmental policy because the survival of such policies will depend on the ability of the policy maker to deal with these issues successfully. *Design* is important to policy makers on *two* accounts. First, it provides guidance for devising policies compatible with the anticipated goals. Second, it foretells potential political economy implications of policies upon implementation. The latter will aid the policy maker to take precautions to ensure the passage of the policy. *Implementation*, on the other hand, is at the core of the administration of policies; it deals with monitoring compliance and the tracking of market performance. Hence, a better understanding of the determinants of instrument choice is required in order to ascertain how environmental regulation is likely to be implemented and who the winners and losers would be (Hahn and McGartland, 1989). It is imperative, therefore, that we pay a particular attention to these issues which have been proven to be critical for the successful design and implementation of market-based environmental policies.

2.5.2.1 Political Aspects

As noted, courts are agents of the legislature which is the principal, depicting a principal-agent relationship. The elected members of the Congress (or parliament), on the other hand, are agents of the voters (the principal), once again, establishing a principal-agent relationship. The nature of these relationships has important implications on the 'instrument choice'. This is because the incentive problems will arise due to asymmetric information when individual preferences differ between the two parties, i.e., the principal and the agent (Fudenberg and Tirole, 1993). In the context of environmental policy, the principal is the one who ultimately decides on the choice of the 'instrument", using her private information. Thus, her choice will be the one that entails the highest expected payoff. (Laffont and Tirole, 1986 and Laffont, 1999). This is particularly relevant in the case of emissions trading programs because the agents (elected members) will only support (or promote) the instrument that is optimal to the principal (voters) who are aware of their agents' type (Maskin and Tirole, 1990).

Public policy formulation in a democratic setting resembles the principal-agent problem discussed above. As we will see, a number of political economy issues tends to influence the policy decision at all stages. These issues may become even more critical in the case of market-based environmental policies, particularly emissions trading programs, because such policies are likely to accompany different social and political consequences, depending on the features of design and implementation. Finding ways to deal successfully with these consequences is a daunting task for the policy maker whose objective is to achieve environmental goals in the most effective way possible.

An example may be useful to demonstrate the importance of political economy issues. When the concept of emissions trading was beginning to gain recognition in the United States, many viewed it as a "license to pollute". This perception affected politicians' willingness to endorse market-based policies which created a reluctance among public policy makers to adhere to these policies to pursue environmental goals. Regardless of the fact that traditional command and control regulation had been criticized on cost effectiveness grounds, these perceptions continued to be dominant until the CAAA to the U.S. Clean Air Act were introduced in 1990, which provided the statutory provisions for creating a market for trading SO_2 permits.

These political aspects become even more critical when one policy is to be chosen over several alternatives. For example, deciding between emissions trading and a tax will largely depend on policy makers' ability to deal with the underlying equity and efficiency concerns and other political economy considerations. This demonstrates that economic efficiency is not the sole criterion for instrument choice. Issues of political structure and equity must be given equal consideration. To this end, a number of political economy issues, which appear to be critical for the evaluation of market-based environmental policies, have been identified for further discussion.

Equity Issues

Equity issues arise in the public policy context when regulatory approaches are used to pursue policy objectives. The regulatory methods essentially involve allocation of resources among economic agents. With regard to commodities that are exchanged through the market, regulation will distort market equilibrium, by either drawing some resources from economic agents to the government, or reallocating resources among economic agents themselves. In the case of open-access resources, the situation is different. Since such resources are not exchanged through the market, using a market-based policy would entail a 'payment' for consumption of the resource.

In a much narrower sense if we were to consider only emissions trading programs, equity issues will arise due to initial allocation of tradeable permits (Pezzey, 2000). For example, if the *gratis* allocation rule is used, there would not be any room for equity concerns since no transfer of resources from sources to the government will occur (assuming that there are no income effects). On the contrary, if permits are allocated by an auction, there is necessarily a resource transfer from firms to the government which would lead to equity concerns. If the government decides not to transfer back these revenues collected through permits sales, the resulting equity concerns would undermine political interests for the pursuance of market-based policies. This is why we generally find that taxes are politically unattractive (Farrow, 1995). While this demonstrates the political significance of equity issues, the issue of permits allocation as a distinct feature of institutional aspects will be considered later in this discussion.

Initial Allocation of Permits

One important political economy consideration central to the design of emissions trading programs is the *initial* allocation of permits among sources. Sometimes designing a formula to allocate initial permits becomes contentious and complex when governments have to decide whether to allocate permits free, or to auction them (Australian Greenhouse Office, 1999a and 1999b). Economic theory indicates that the initial allocation of tradeable permits does not affect the final outcome, i.e., overall cost savings or gains from trade, since economic agents have the incentive to minimize their emission costs, the initial allocation notwithstanding. But cost savings can be affected if the allocation alters the transaction costs (Stavins, 1995).

Two methods widely used in the allocation of emissions permits are grand-fathering and auctions. While grand-fathering involves a *gratis* allocation of emissions rights, auctions require bidding by polluters to acquire permits. Despite the indifference between the two methods in terms of the final outcome, which is independent of the initial allocation in the absence of transaction costs and income effects, each method differs substantially in terms of equity considerations. For example, an important difference between an auction (with no transfers) and the grandfathering of permits lies in the way the 'rents' are distributed (Boyce, 1998). The term 'rent' in this context refers to the 'surrender value' involving the exchange of emissions permits. When permits are auctioned, the government collects 'rent' by selling the permits and when permits are grandfathered, rent will be distributed among sources according to the allocation rule. Now, if the rent collected by the government is not redistributed, equity concerns arise due to the net transfer of resources from sources to the government.

However, if permits are distributed through a conventional auction, i.e., no redistribution of proceeds, the incentive for "green" products may be improved more than it would had the emissions permits been allocated free of charge, i.e., grandfathered. This is because that the returns to the 'non-green' products will be lower since a portion of the return has to be spent on buying permits from auctions. But, if permits were grandfathered, there would not be any additional cost to buy permits and thus, the returns to 'non-green' products, in the short term, would remain the same. Thus auctions have a higher potential to enhance *short-term* efficiency than would the *gratis* allocation of tradeable permits (Hahn and McGartland, 1989). These equity and distributional issues prove to be vital in building acceptance among stakeholders for choosing permits over taxes.

Once the method of allocation is chosen, the policy maker's task is to design a basis for the allocation of permits, i.e., how individual entitlements are determined, particularly if *gratis* allocation is decided upon. A variety of options exists, including allocation on past emissions or anticipated/projected future emissions. If permits are pro-rated with past emissions, then firms have an incentive to overstate actual emissions in order to receive more permits. In contrast, if permits are to be allocated on projected emissions, firms have an incentive to defer any investment in green technologies in order to benefit from a larger share of permits.

Some economists see the free allocation of permits as a compensation for capital losses incurred due to a change in public policy. In addition, administrative ease may also play a role in decisions to allocate permits freely. On the other hand, if a government decides to auction permits, its motivation could be cost recovery. The mode of allocation of permits matters in terms of the resulting distributional effects, as we discuss next.

Revenue-Recycling

If the government decides to impose pollution taxes or to auction the marketable permits, emitters' willingness to pay will determine how much revenue the government will collect. In some cases, the revenues collected by taxing or selling permits are transferred back to the affected agents in order to minimize effects on equity. A popular method that governments use to redistribute these revenues involves making lump-sum transfers, or cutting existing marginal tax rates (Bovenberg and Goulder, 2000). This procedure involving revenue transfers by the government is often referred to as *revenue-recycling*. The goal of this procedure is to achieve tax neutrality and to compensate the losers from an environmental policy. It has been argued that such lump-sum transfers, if used properly, will not only eliminate distributional and equity concerns of environmental regulation because they reduce the burden borne by firms and/or consumers, but they will also enhance the chances of political survival of policies advocating environmental goals.

Nevertheless, it is often difficult to ascertain the effects of lump-sum transfers with certainty, and thus, a careful inquiry into the particular circumstances is essential in order to determine whether the revenue redistribution would involve under-compensation or over-compensation for the parties concerned. Furthermore, the pre-existing market distortions tend to magnify the likely distributional effects of market based policies, because pre-existing market distortions are present virtually in every product market that is being regulated. In other words, frictionless markets are virtually non-existent and the policy maker's ability to assess the resulting equity effects is severely constrained.

The policy-induced equity effects due to the presence of pre-existing market distortions, particularly due to taxes, are termed 'tax interaction effects'. These effects, if estimated, will point to the magnitude of the 'hidden cost' that tends to erode the potential efficiency benefits of the environmental policy being implemented (Burtraw, 1999). For example, Goulder *et al.* (1997) have predicted that the magnitude of the tax interaction effect will be $1.06 billion US per year (1995 dollars) during Phase II of the U. S. SO_2 program. This is a substantial loss to the economy since it adds another 70% to the estimated cost of compliance by the electric utilities. Thus, revenue-recycling is a greatly important issue since the correct actions could save millions of dollars to the taxpayers.

The difficulty with reallocating revenues, particularly collected by taxes and auctions, is sometimes used as an explanation for policy makers' preference towards grand-fathering permits, where the issue of revenue-recycling does not arise. To strengthen the merits of marketable permits in this context, it essential that transaction costs be kept low so that market prices of permits are (approximately) reflective of the marginal cost of abatement. It appears that tradeable permits systems offer a greater flexibility in this context, as compared to taxes, for equalizing marginal cost of abatement through trading. [19] Thus, the flexibility is the key to success of the permits market (Cramton, 2000).

[19] A qualification is in order. As shown in Doucet *et al.*, (1997), the 'standard' equilibrium result that the marginal cost of abatement equals permit price could be affected by source location, which is a reflection of the spatial dimension of coal markets. The results of the econometric model in Chapter 3 further confirm this fact.

2.5.2.2 Institutional Aspects

Institutions which include governments, the judicial system, regulatory bodies, and other stakeholder entities such as resource exploiters play an extremely important role in public policy formulation. The goal of this section is to identify the significance of the institutional aspects for the design and implementation of market-based environmental policies. Broadly speaking, institutions play a *dual* role at the '*instrument choice*' stage of policy formulation in: (1) exploring the feasibility of all potential policy alternatives compatible with the targets identified at the '*policy target*' stage, and (2) addressing political economy considerations arising from the issues of equity and effectiveness, as discussed in the foregoing section.

In the case of emissions trading programs, institutional aspects bear a key significance since the choice of these programs over other alternatives may only be possible if the existing institutional structures are conducive to and desirable for such programs. For example, the initialization of the U.S. SO_2 program under the CAAA, and the subsequent assignment of the programs' administration to the EPA is seen as an attempt to overcome state prerogatives for imposing environmental regulation. This may hold true since the U.S. Congressional Committee on the Environment had no authority over taxes and hence, an alternative was essential in order to overcome the underlying institutional barriers (Nelson, 1987, pp. 66-71).

Similar situations would also arise when the existing institutional structure is unable to accommodate market-based environmental policies. The U.K experience with market-based policies provides a classic example in which the country's existing regulatory framework and the institutional setup have jeopardized government's efforts to introduce a permits trading scheme to control SO_2 emissions. As noted by Sorrell (1999), UK initiatives have failed miserably due to a series of obstacles, most of which arose from the conflicts between emissions trading and pre-existing regulatory principles, that ultimately proved to be unsurmountable. Sorrell argues that the inability of the UK regulatory framework to accommodate the flexibility inherent in permits trading has contributed to this downfall. These lessons show the significance of institutional structure for the realization of environmental goals through emissions trading. This argument is consistent with the latest research findings that stresses the importance of pre-market distortions (McCann, 1996).

Price vs. Quantity Debate

The choice between *price* and *quantity* instruments and their relative performance in distinct circumstances is an important topic for the current debate of market-based environmental policy. Much of this debate is devoted to contrasting pollution taxes (the major *price* instrument) and emissions trading programs (the major *quantity* instrument). Economists (for example see Pizer, 1999) argue that the uncertainty over future economic conditions and technological innovations would make price instruments, particularly emissions taxes, perform better than quantity instruments such as tradeable permits. Despite the fact that price instruments will not offer the policy maker any assurance of the likely reduction in emissions (because emission caps are not established under taxes), they argue that certain environmental problems such as Kyoto commitments, can be dealt more effectively with the use of price instruments. To some extent this argument hinges on the assertion that the existing market conditions in developing countries where most of the emissions are generated, are more conducive to price instruments.

However, some economists, for example, Stavins (1996), have argued that the *positive* correlation between costs and benefits of environmental policies in the presence of uncertainty renders the quantity instruments (i.e., tradeable permits) more appealing than price instruments (i.e., taxes). Ellerman *et al.* (2000) find that tradeable permits are apt to respond better to the uncertainties of the real world. One important reason for this is the flexibility offered by the former that helps sources to choose from a wide array of means, in this case the least uncertain means, in order to comply with the regulation. The important implication is that the actual market conditions are typically subject to market imperfections, and thus, costs and benefits uncertainty would favour marketable permits. Furthermore, as we will see, political considerations will make price instruments such as emission taxes highly unattractive in many countries, since firms resist revenue transfer to the government induced by taxes. Furthermore, quantity instruments, particularly tradeable permits, are likely to overcome such feasibility problems since, in most cases, they are being allocated *gratis* to firms, and thus no transfer of firm income to the government occurs. Prudent policy makers, therefore, should consider both economic gains and political feasibility simultaneously, before a decision is made on the choice of an economic instrument to deal with environmental issues.

"Caps" vs. "Standards"

A key element of tradeable permits systems is the quantity constraint or the *cap*. [20] In theory, a cap dictates a limit on a particular pollutant which is brought under an emissions trading program. Nonetheless, a close examination of the principles governing 'caps' will reveal that the they are nothing but approximations of the standards established for factors involving environmental and health effects. For example, ambient air quality is monitored by standards based on scientific evidence regarding particulate concentrations in the atmosphere. Often, these standards are established on the basis of costs-benefits analyses which determine the 'desirable levels' of health and environmental quality.

The cap of the U.S. SO_2 program is designed to obtain a ten million-ton annual reduction in sulfur dioxide emissions. [21] This reduction in SO_2 is to be achieved through two Phases in the following manner: during Phase I (1995-1999) the average permissible

[20] Sometimes, economists refer to tradeable permits programs as a *cap-and-trade* approach to environmental regulation. For details, see Ellerman, *et al.*, 2000.

[21] For details, see Title IV of the Clean Air Act Amendments of 1990.

emission rate was 2.5 lb. per million Btu, and during Phase II (2000-2010) it was tightened to 1.2 lb. per million Btu. Clearly, these permissible emissions rates correspond to the U.S. standards on SO_2 concentration rates in the atmosphere. Since the SO_2 program requires approximately 40% reductions in emissions by the year 2010, as compared to 1990 levels, this means that, unlike most other traditional methods including technology standards or emissions rate standards, the cap is a guarantee that SO_2 emissions will not increase vis-à-vis economic expansion. Hence, caps are considered as proxies to national standards.

Hybrid or 'Safety-Valve'

The choice of economic instruments is primarily a task entrusted to policy makers whose objective is to achieve certain environmental goals with a minimal use of resources. With perfect information of future costs, the choice of instrument appears to be trivial, as either price instruments (e.g., pollution taxes) or quantity instruments (e.g., tradeable permits) would yield the same outcome. Nevertheless, this is far from being the case in reality. As actual market conditions are subjected to numerous factors, the resulting asymmetric information lead to uncertainties, rendering accurate predictions of future costs and benefits of policies nearly impossible (Sappington and Stiglitz, 1987, and Portney, 2000). [22] These benefits and costs are often correlated, and influence both the 'policy target' and 'instrument choice', which are the first two stages of our analytical framework. In particular, in the context of market-based environmental policies, these uncertainties influence the abatement cost, the adequacy of the cap, health and environmental benefits, and could even lead to complexities about technological progress and investment. As a result, the choice of instrument becomes a major concern, as it leads to variable effects on

[22] Stavins (1996) notes that '*benefits uncertainty*', even though not often acknowledged by economists, is more substantial than '*cost uncertainty*' which was emphasized by Weitzman (1974) in the context of environmental policy.

costs and benefits, i.e., social welfare (Wietzman, 1974, Stavins, 1996 and Pizer, 1997). The interesting question then is how to make the 'right choice' of policy instrument.

A recently advanced economic argument favours a hybrid (often referred to as a 'safety-valve') of *price* and *quantity* instruments as an effective solution to this problem of choice. It has been recommended that the policy maker should rely on a 'safety-valve' strategy where quantity instruments (say emissions permits) and price instruments (say a pollution tax) are combined to attain an environmental goal in a way that is both economically sound and politically feasible. In essence, the policy maker can issue a fixed number of emissions permits either by auction or by grand-fathering, and also have the option to provide extra permits to any firm willing to pay a fixed ceiling or 'trigger" price. On the one hand, grand-fathering or auctioning of initial emissions permits provides policy makers with the flexibility to offer partial rights to emit, thereby addressing the concerns of firms over government revenue transfers. On the other hand, the sale of extra emissions permits at a predetermined price offers the emissions trading program the same compliance flexibility inherent in emissions taxes.

In a series of recent studies, economists [23] have examined the possibility of combining tradeable permits and pollution taxes to further reduce the regulatory cost burden while improving efficiency of market-based environmental policies. These authors suggest that it is desirable to have an *incremental* price for the 'safety valve permits', if permits are aligned with pollution taxes in environmental policy. In other words, they recommend that the value of such permits should increase in line with the rate of interest. The interesting insight here is the consistency of this incremental pricing phenomenon with Hotelling's (1931) rule for non-renewable resources, i.e., clean air, ozone, etc..

Central to Hotelling's (1931) argument is the economic rent, which approximates the difference between market price and extraction costs. In other words, the rent is a user cost,

[23] See, in particular, Pizer (1997) and Bovenberg & Goulder (2000).

i.e., the intertemporal opportunity cost of extracting now rather than later or the future benefit that could have been enjoyed had the environmental resource been used sometime in the future. Hotelling noted that when a resource (e.g., clean air) becomes progressively depleted its market price (say approximated by the permit price) net of cost will have to rise at the rate of interest. The increment (difference between the permit price and the cost which is zero in this case) would then reflect the relative scarcity of the resource.

2.5.2.3 Product Market Characteristics

One other important area which influences *both* the 'choice' of instrument and the 'performance' of any environmental policy is product markets. The link of the former is direct while that of the latter is indirect. The term 'product markets', in the spirit of its usage in this chapter, refers to commodity markets in which production involves substances (or by-products) of environmental concern. A case in point is electricity generated by coal. In this case, the primary output market is electricity, the primary input market is coal, and the by-product is sulfur dioxide emissions. In other words, two product markets are linked to the 'environmental bad' being regulated by market-based instruments.

The influence of product markets on 'instrument choice' is two-fold. First, it is natural that policy makers consider consumer preferences (primarily to maximize consumer surplus) and producer preferences (primarily to maximize producer surplus) in product markets in order to ascertain the likely impacts of the planned regulation. This way, the 'instrument choice' is being "shaped" by product market conditions. Second, the existing market distortions such as taxes, entry barriers, etc. will determine the relative strengths of economic instruments which are being considered for environmental purposes (Hahn, 1990, Rasmusen and Zupan, 1991). In this case, the product market structure will act as a feeder to the 'instrument choice' by the policy maker. Furthermore, there is a weak link (as indicated by a dotted arrow in Figure 2.2) between product markets and the likely 'performance' of the policy. A useful way to understand this link is to visualize industry preferences for various regulatory instruments.

In general, industrialists tend to focus on the likely effects of environmental regulation on profits, as their primary motive is to maximize the return on their investment. On the other hand, the green activists who closely monitor industry activities are primarily concerned with the impacts of environmental policy on the environment. Often, there is a trade-off between the viewpoints of these two groups. This poses a challenge to the policy maker whose objective is to ensure the easy passage of the policy. Regardless of the basis on which the policy instrument is chosen, one of these groups will find that their concerns have not been accommodated by the decision. Their dissatisfaction may trigger actions that could affect the performance of the policy since these actions may not fulfil their desires (Hahn and McGartland, 1989, Hahn, 1990). In what follows, the most important aspects of product markets will be taken up for further discussion. They are *demand and supply characteristics* and *pre-existing market distortions.*

Demand and Supply Characteristics

Economists have found that demand and supply characteristics of commodities are critical for the success of any environmental policy (see for example, Goulder *et al.*, 1997, and Bovenberg and Goulder, 2000). They argue that the ability of pollution taxes to bring about regulatory goals largely depends on both the demand and supply elasticities of the underlying commodities. For example, if the supply of a taxed commodity is *elastic*, most of the tax burden would be borne by consumers and the effects on industry profits would not be substantial. This means that a firm's incentive to look for environmentally-friendly production methods or abatement technologies under these circumstances remains low, since its profits are largely unaffected by the tax.

Let's consider how this argument hinges on demand characteristics. If the demand for the underlying commodity is *inelastic*, then the tax-induced price increase borne by consumers would not alter the quantity demanded substantially. This means that consumers not only pay the tax, but continue to demand a relatively high quantity, perhaps the same quantity that was demanded before. If these conditions dominate the market for a taxed commodity, the likelihood of achieving certain reductions in pollution would be slim, notwithstanding the equity and distributional impacts created by the pollution tax.

On the supply side of the U.S. SO_2 program, coal producers have the potential to influence the functioning of the program through strategic actions (i.e., under the guise of permit brokers, they could purchase permits in large quantities). The motive for this behaviour is to influence the decisions of the sources to use high-sulfur coal vs. low-sulfur coal, as part of their compliance (Doucet *et al.*, 1997), by changing the conditions of the permits market.

Furthermore, the anticipated reductions in sulfur dioxide emissions, as defined by the cap of the U.S. SO_2 emissions trading program, are found to be sensitive to the demand and supply conditions in both the input and output markets of the electricity sector, i.e., the coal, oil and gas markets, and the electricity market in the United States. If anticipated adjustments in these markets do not occur, then the firms' ability to undertake required changes in productivity mixes [24] in line with the terms of new regulation would be difficult. On the other hand, since tradeable permits systems are designed to perform within the presence of well-defined property rights, these imperfect product market conditions are likely to prevent emissions trading programs from reaping all the benefits of trade (largely cost savings and productivity gains). It is therefore essential that the policy maker be aware of the underlying market conditions before choosing a particular economic instrument to attain environmental objectives.

[24] This is an option available to firms in addition to using permits.

Pre-Existing Market Distortions

Economists have also examined the potential role of pre-existing market distortions (such as existing taxes) in environmentally motivated taxes. In reality, most commodities, if not all, are traded under imperfect market conditions, where distortions through taxes already exist at the time of environmental regulation, say because a pollution tax is introduced. An important question arises as to how such market distortions would affect environmental goals set to be achieved through market-based instruments. Several economists (see, for example Goulder *et al.*, 1997, Goulder and Parry, 1999, and Bovenberg and Goulder, 2000) have begun to study this issue, focussing on pollution taxes in the presence of pre-existing market distortions. [25] They have found that distortionary taxes raise the costs of pollution abatement under both emissions permits and pollution taxes, and that the underlying cost differentials across these instruments largely depend on the extent of the abatement called for by the policy where low levels of abatement are typically characterized by larger cost differences between economic instruments.

[25] Often, economic activity in the presence of market imperfections or market distortions is described as the '*second-best world*'.

2.5.3 Performance Criteria

Nearly a decade after widespread use of market-based economic instruments in the United States, particularly tradeable permits programs, a series of new insights into the future design of these two instruments has started to emerge. Recent evidence suggests that most of the major U. S. environmental policies relying on these instruments have recorded impressive gains, while a handful of others have experienced several drawbacks. Economists have embarked on a 'learning-by-refining' process in order to determine 'what went right' and 'what went wrong'. Motivation for this process is to inform policy makers of how future environmental policies incorporating economic instruments should be designed in order to achieve environmental goals more effectively. A number of economists are currently considering the circumstances under which market-based instruments perform alongside set policy targets. In what follows, we will briefly summarize several important arguments which emerged from this new 'economic thinking' and consider their significance for future environmental policy.

In this context, the performance of public policies must be evaluated in terms of their achievements, particularly the accomplishment of policy goals. In the case of economic instruments, economists have used a wide array of criteria to judge the performance and social desirability of policy goals. Nonetheless, a gap exists in the literature in terms of the coverage, because studies have focussed almost exclusively on selected criteria as opposed to all potential criteria that permit an all-round evaluation of the performing economic instruments. Hence, a major task of this study is to consolidate all important aspects of economic analysis, in order to enable a fair evaluation of emissions trading programs. The following criteria have been identified as the most important in evaluations of market-based environmental policies:

- ❑ Cost Effectiveness
- ❑ Efficiency Gains / Innovative Aspects
- ❑ Property Rights Characteristics
- ❑ Micro and Macroeconomic Impacts
- ❑ Ancillary Health and Environmental Benefits

Cost Effectiveness

If an environmental policy has the potential to minimize the costs of a certain level of domestic production and use of regulated pollutant(s), the policy is considered cost-effective. In other words, cost effectiveness requires a desirable short-term allocation of scarce resources. The transition of environmental regulation from command and control type methods to innovative market-based policies is ignited by the latter's potential to deliver lasting solutions to environmental problems with the least possible cost. To this end, economists have made a considerable effort to analyze cost elements associated with various economic instruments, including tradeable permits systems.

In general, two types of costs exist, namely *compliance costs* and *economic costs*. Compliance costs include the expenses that firms have to incur in order to comply with the regulation. In the context of tradeable permit systems, these costs will include the cost of buying permits, costs of abatement, switching fuels, and investment, and other costs of administration, often referred to as *transactions costs*. [26] Economic costs, on the other hand, will include the opportunity costs of regulation, i.e., the value of goods and services lost to the economy due to regulation. Examples of this category are hidden costs or benefits attributable to indirect productivity changes resulting from policy compliance, pre-

[26] This last element, transaction costs, arises when property rights are not well-established. We will discuss this issue in detail later in this section.

existing market distortions (e.g., presence of taxes), and costs arising from product market characteristics.

The dominance of *emissions trading* as a powerful incentive-based economic alternative is attained by the cost effectiveness of this instrument. For the most part, the cost effectiveness is due to the *flexibility* accompanied by emissions trading programs, which allows sources to choose from a wide array of options, and to exploit all beneficial opportunities as part of the compliance with the regulation (Ellerman *et al.*, 2000). For example, sources can decide, in addition to holding permits, to invest in abatement capital, improve the existing technology (e.g., scrubbers), search for new (green) technologies, switch fuel sources (for example, from coal to natural gas) or adjust the output, or any combination of these as a means of compliance.

The recent debates over market-based policies will reveal that cost effectiveness is the single most important criterion responsible for winning the policy makers' recognition for these type of policies, notably in recent years. This is particularly true in the case of the U.S. SO_2 permits program, which has demonstrated the strengths of this economic instrument through large cost savings. [27] Nonetheless, the critical importance of cost effectiveness for market-based environmental policies has been undermined by a divided stand in the literature on the relative importance of various cost elements.

One branch of studies (see Carlson *et al.*, 1998, Ellerman *et al.*, 1999 and Stavins, 1995) almost exclusively focuses on compliance costs, implicitly assuming that only compliance costs matters in public policy formulation. Another branch devotes their exclusive attention to economic costs (see Goulder *et al.*, 1997, Goulder and Parry, 1999 and Pizer, 1999), in attempting to explain the extent of so called 'hidden costs' of market-based regulation, particularly due to imperfect market conditions prevalent in most of

[27] In a very recent and comprehensive study, Ellerman *et al.* (2000) estimate cost savings of the SO_2 program to be about 55% or $20 billion over a thirteen-year horizon, or if put differently, the SO_2 program has cut compliance costs by about one-half.

product markets. This dichotomy has left a gap in the literature as to how a meaningful evaluation of emissions trading programs is undertaken to judge public policy performance. It has also led some economists to cast doubt on the existing estimates of the real economic costs of environmental regulation. They argue that the estimated impacts of environmental regulation on production costs have overstated the actual economic costs of market-based regulation (see Morngenstern *et al.*, 1997). Moreover, the current literature lacks a quantitative basis for the type of estimates needed to shed light on all costs simultaneously. In particular, econometric techniques to estimate the relevant magnitudes of cost elements have not been developed.

However, a methodological evaluation of cost effectiveness of emissions trading programs under actual market conditions (i.e., in the presence of market imperfections, pre-existing regulation, and other characteristics peculiar to the input and output markets), which simultaneously takes into account the political dimensions, is yet to be undertaken.

To this end, this dissertation makes a two-fold contribution. First, this chapter, through the proposed analytical framework, recognizes cost effectiveness as a primary determinant of the evaluation of tradeable permits systems. In Chapter 3, we will attempt to fill this gap by introducing econometric and time-series techniques into the evaluation of cost effectiveness of tradeable permits programs under 'actual' political and market conditions. In particular, we will develop a translog cost function model incorporating all of the important cost criteria, in order to ensure that the aspects of cost effectiveness are properly investigated in terms of economic theory. The implications of the translog model will be tested using the data from the U.S. electric utility industry subjected to the CAAA, as described in the Appendix I.

Efficiency Gains / Innovative Aspects

One important feature that distinguishes tradeable permits systems from the remainder of the market-based instruments is the incentive of the former for technological innovation.

When confronted with a wide array of options for complying with the regulation, the profit maximizing behaviour of firms induces them to consider all of the possible scenarios before making a choice. Because of the 'flexibility' in compliance under emissions trading, firms tend to explore ways to reduce the existing levels of emissions. As part of this process, firms will consider, among other things, methods to (*a*) improve the current technologies, or (*b*) invent new 'green' technologies to replace the current ones. While (*a*) is more of a short-term objective, (*b*) constitutes a key component of long-term planning. The latest evidence from the U.S. SO_2 program indicates that more than 45% of emissions reductions occurred during Phase I have been achieved by installing scrubbers, a significant improvement to the existing power generating technology (see Table 2.5). This evidence will illuminate Phase II of the SO_2 program, in that more innovations in the electric utility industry should be forthcoming as the program progresses into the future. Moreover, this evidence manifests the significance of technological improvements possible under tradeable emissions permits programs.

Some economists have advanced hypotheses to highlight the significance of technological innovation under market-based environmental policies. One such hypothesis, often referred to as the *Porter Hypothesis*, claims that these policies could actually work in favour of industries by providing the flexibility for firms to seek out new technologies as a means of compliance (Porter and Class, 1995). This hypothesis further asserts that market-based-policies, such as emissions trading programs, will create incentives for firms to develop superior and environmentally-friendly technologies, which, in the long run, will contribute to a higher productivity and larger market shares.

According to economic theory, the contribution of technological improvements could occur in two ways: (a) in terms of a higher productivity, i.e., lower per-capita usage of inputs, (b) in terms of a lower cost of production, e.g., scrubbers, where utilities, by reducing their current emissions, spend less on purchasing emissions permits. The current literature on technological aspects of emissions trading does not provide enough guidance to ascertain the actual impacts of technological improvements on power generation that occurred due to the passage of the CAAA.

Despite the critical importance of efficiency aspects for the choice of market-based policies for environmental protection, a formal methodology to disaggregate technological improvements into productivity gains and cost efficiency is yet to be developed. Moreover, a methodological evaluation of efficiency gains (technological improvements) attributable to emissions trading programs is essential in order to judge the relative performance of market-based policies under actual market conditions. In attempting to bridge this gap, this dissertation undertakes two tasks. First, the proposed analytical framework (Figure 2.2 on page 27) recognizes 'efficiency' as a prime component of performance criteria. Second, Chapter 4 will develop a theoretical basis for the estimation of efficiency gains / technological improvements ignited by the U.S. SO_2 program by using Data Envelopment Analysis (DEA) methods. The chapter will also outline linear programming methods to separate efficiency gains from cost effectiveness.

Property Rights Characteristics

The notion of tradeable permits has its roots in the premise that the creation of property rights is essential to address environmental concerns (see Dales, 1968 and Tietenberg, 1985). A major way to distinguish tradeable permits from other modes of environmental policies, as having the potential for yielding effective solutions, is by ensuring that the former is established within a well-defined property rights system. To be well-defined, tradeable permits should inherit the *four* essential characteristics of property rights outlined above, namely *exclusivity*, *transferability*, *flexibility*, and *enforceability*. [28]

[28] Exclusivity requires that all benefits and costs accruing to the ownership of a resource should be accrued to its owner. Transferability is to ensure 'worry-free' exchange of rights through voluntary exchange. Flexibility is a feature of the property right that is adaptable to changes in decisions by the owner. Enforceability secures the owner's ability to exercise his right to prevent others from using or encroaching on the resource. If a property rights scheme is characterized by these features, it may be considered as *well-defined.*

In turn, these characteristics become the fundamental determinants of the 'quality' of the property rights being created. If, for example, the created property rights system lacks either one or more of these elements, the anticipated policy goals or gains from trade would not be materialized. The examples presented in Table 2.3 below show mixed results across major North American emissions trading programs. In cases where the programs have fallen short of expectations (for example, the Fox River program), either absence or the lack of essential property rights characteristics have played a major role. Thus, it is required that emissions rights be reflective of these characteristics in order for emissions trading programs to function effectively. A meaningful evaluation of tradeable permits programs therefore should consider the "quality of the right created" in terms of the four characteristics identified above.

Life-Span of Permits

Another important dimension of property rights governing permits allocation concerns the *duration* or the *life-span* of the marketable permits being allocated. In general, the controlling authority has to 'specify' a time-period during which the permits are exchangeable between the parties, i.e., expiry date of permits. In rare instances, however, permits may be issued without any expiry date. To the extent that permits are distinguished in terms of their life-span we can observe *three* categories of permits, namely *short-term*, *long-term*, and *perpetual*. Short-term permits will last between a year and two years from the date of issue, while long-term permits are typically exchangeable for a finite number of years. Perpetual permits, on the other hand, provide emitters with the advantage of indefinite usage. In other words, they provide certainty.

The permits of varying duration have different implications on the performance of tradeable permits systems. The main channel through which duration affects program performance is permits trading. There are at least two important ways that this could take place. A firm's decision to bank permits would depend on, among other things, the time period that the permits can be stored for future use. For example, if permits are set to expire soon, then the incentive to bank them diminishes. As a result, the quantity response to changes in permit prices would be subtle, since not enough buffer stocks would be available due to low 'banking'. This would affect the ability of sources to engage in trading or to adjust emissions across periods. From another point of view, "bankable permits" greatly reduce price instability. This helps firms to engage in trading as uncertainty over controlling emissions is reduced, resulting in higher gains from trade as firms are able to allocate permits optimally over time (Godby, *et al.*, 1997).

These behavioural responses would lead to uncertainty among sources as to the nature of future government policy, i.e., new allocation rules governing the life-span of permits. This uncertainty would erode the incentive to trade further, not to mention the transaction costs that would result from the efforts of sources which are searching for information to minimize their risks of trading. These observations, perhaps, would not be obvious if one were to examine tradeable permits systems "in theory". However, depending on the life-span, the sources can benefit in the short run from planning their alternative pollution abatement strategies. Thus, although tradeable permits may have a finite, and often short, duration, they may well represent a successful policy. Because firms cannot switch instantaneously to cleaner technologies, the right to pollute at present time has value, even though it may not last for a long period of time.

A clear distinction could be made between at least two of the major tradeable permits programs which originated in the United States, based on the characteristics described above concerning the life-span of tradeable permits. These two programs are the Fox River Program and the SO_2 program. A frequently offered explanation for the extremely low level of trading, and the subsequent collapse of the Fox River Program, concerns the uncertainty surrounding the discharge permits. In this case, discharge permits were initially issued without an expiry date, and halfway through the program authorities announced a date of expiration for the permits which had already been issued. The uncertainty that resulted contributed to the collapse of the program.

On the contrary, the SO_2 program has, among many other attractive features, clearly defined dates of expiration. The program was designed in two Phases, i.e., Phase I and Phase II with an objective of reducing ten million tons of SO_2 emissions annually from 1990 to 2010. The annual EPA auctions involve *four* different types of permits, namely spot market (usable during the year of auction only), seven-year advance (usable seven years later), six-year advance auction for seven-year permits (left-overs of six-year advance that are sold a year later), and private (source to source) trading. The initial permits allocated at the outset of the program are valid during both Phases. These clearly defined rules have substantially lowered the uncertainty over permit validity (life-span) and, thus have enhanced the program performance immensely.

Transaction Costs

A system of *well-defined* property rights brings about a socially efficient outcome through voluntary exchange, independent of the way in these rights are distributed (Coase, 1960), assuming *no* wealth effects. The importance of this argument is that the absence or lack of property rights would affect voluntary exchange since it entails *transaction costs.* Transaction costs are the costs of establishing and maintaining property rights, and the costs resulting from the transfer of property rights (Allen, 2000). Market economies are typically characterized by transaction costs which arise from the 'exchange of rights' because parties to such exchanges need to communicate and exchange information. In some cases, inspection of commodities, entering into contracts, and seeking legal advice are common to exchanging property rights. [29]

[29] Consider doing business in Russia vs. in North America, and compare the underlying transaction costs resulting from dealings with bureaucracy, establishing respect for contracts, etc.

Buying automobiles, real estate transactions, and waste disposal are cases in point. Essentially, transaction costs involve some inputs or resources that are costly, which, in some cases, may be reflected as a premium in the market prices (Alston and Gillespie, 1989). Transaction costs could also arise from any government intervention to correct inefficiencies (Tietenberg, 2000, p. 82).

Moreover, as is argued in the next section, in the context of tradeable permits, most transaction costs arise as a consequence of a lack of *certainty* (or the presence of uncertainties) in the emissions rights that are being created. In particular, we have evidence to suggest that there are at least a couple of instances, namely the Fox River and the Lake Dillon Reservoir emissions trading programs (see Table 2.3 in Section 2.5) where high transactions costs are blamed for the collapse of the programs. A major contributing factor to such costs was the uncertainties that the permits were subjected to. The lesson from these programs is that it is imperative that transactions costs be kept low in order to realize policy goals, implying that a complete evaluation of any emissions trading program should take into account the effects of transactions costs.

Certainty Criterion

One of the essential elements ensuring the voluntary exchange of permits in the market place is the 'degree of certainty' accompanied by the permits. In other words, the success of any tradeable permits system is contingent upon policy maker's ability to eliminate or minimize 'uncertainties' (or create certainty) that affect the decisions of buyers and sellers of permits. Major sources of 'uncertainty' arise from the life-span of permits, the presence of transaction costs, trading rules, tax policy and the rate of return regulation governing abatement equipment and investment in green-technology, the number of sources (firms) eligible to engage in trading, and future permits allocation rules. The challenge faced by the policy maker in these circumstances is to define simple, concise, and adequate rules as to how each of these items with the exception of transactions costs will be dealt with during the course of the permits program. In short, this procedure amounts to ensuring that property rights are "perfect". In this sense, it is easy to see transaction costs as resulting from "ill-defined" rights or due to the presence of uncertainties (i.e., the lack of certainty). In this way, certainty is linked to the "quality" of the property right(s) which are being created.

Broadly speaking, all uncertainties arising from the factors listed above can be classified into *two* types, namely *market* uncertainty and *regulatory* uncertainty (Laffont and Tirole, 1994). The former arises because of 'incomplete information' regarding the future aggregate demand for tradeable permits which will depend on future emissions, and the cost of compliance strategies which will depend on the potential of new abatement technologies. The resulting uncertainty give rise to asymmetric information among trading partners who would then be reluctant to engage in trading. Consequently, this may lead to 'thin' trading or the collapse of the trading system, as in the case of the Fox River program.

The latter, on the other hand, could arise due to ill-defined legal rights for permits, which could lead to substantial uncertainty over the actual endowments of emissions permits and the equilibrium price in the permits market. Consequently, a 'distorted' market price of permits would emerge with a risk-premium to account for the uncertainty (Lund, 1993). A classic example is the CAAA definition of the "SO_2 permits" where the permits are not given the identity of "property rights" to avoid potential compensation claims by firms from the government when the emissions standards are tightened in the future. Even though this has not appeared to have created a substantial impact on the SO_2 permits program (because it is well-designed on many other important respects), the gap between the realized cost savings and the potential cost savings of Phase I may be attributable, at least in part, to the CAAA definition of emissions rights (Svendsen, 1998).

The political significance of the "certainty" criterion arises from the fact that the current structure of the U.S. Congress permits different legislators to exert varying degrees of political support for policies by voting or exercising veto power, depending on the legislator's level of hierarchy. This political support will effectively influence policy targets being considered, where the policy instrument chosen will be the one that has garnered the highest political will. In general, elected officials offer more importance to creating certainty and equity than opportunity and efficiency (Willey, 1992). This is particularly significant for environmental policies because such policies typically involve political, social, and economic dimensions, all of which simultaneously contribute to the "well-being" of the policy upon implementation. In order to recognize the importance of the "certainty criterion" for the survival of emissions rights, we consider it as one of the critical factors affecting the performance of the tradeable permits systems (see Figure 2.2).

Micro and Macroeconomic Impacts

Debates over potential impacts of market-based policies on the U.S. economy have taken two stands. One stand is that the slow progress and the resentment of public policy makers to implement market-based instruments is due to the fear that these policies would bring about negative effects on the economy, particularly on employment, investment, technology, energy consumption and GDP itself.

To this end, some analysts have forecast substantial losses in industry productivity owing to the "additional cost burden" of environmental regulation, which they claim would also erode country's competitive advantage in international markets (see, Yaisawarng & Klein (1994), and Barbera & McConnell (1990)). Furthermore, following the passage of the CAAA, there were concerns that the SO_2 regulation had increased the cost of power generation of the electric utility industry (Jaffe *et al.*, 1995).

It has also been found that the annual average growth rate of 2% in the electric utility sector during the 1985-90 period slumped to 1% during the 1991-1996 in spite of a growing U.S. population period (U.S. Department of Energy; http://www.doe.gov). Given the annual average GDP growth of 2.5% which was steady throughout both periods

(Congressional Budget Office; http://www.cbo.gov) and the annual average growth of 0.23% and 0.27% in the energy sector during the respective periods (Energy Outlook, 1997; http://www.ntis.gov), critics argue that the decline in the productivity is due to the adverse effects brought about by the CAAA. Job losses were also predicted in the high-sulfur coal sector, as utilities moved to a higher consumption of low-sulfur coal (Tietenberg, 2000, page 394). However, the resulting macro effects (on GDP) may depend on the length of non-employment spell for these workers and the existing wage laws (see Grenier, 1982, Hahn, 1987, and Gray & Grenier, 1998).

Another viewpoint maintains that the SO_2 program has created an impetus for new, cleaner technologies, and that such innovations have significantly increased the post-regulation productivity in the U.S. electric utility industry, thus eliminating all of the alleged cost pressures placed on the industry by the new regulation on SO_2 emissions (see for example, Berman and Bui, 1998). With regard to the market-based policies, these arguments stress the need for the inclusion of all potential macro variables with the linkages to the SO_2 program one way or the other.

Ancillary Health and Environmental Benefits

A major objective of most environmental policies is to avoid or minimize human exposure to pollutants or harmful toxic substances generated by some economic activities, which are alleged to be causing health effects such as mortality, morbidity, or an increased incidence of communicable diseases. To this end, the SO_2 program was launched with the primary purpose of finding a lasting solution to the acid rain problem by reducing sulfur dioxide emissions in the United States. The underlying motive is to reduce the SO_2 induced health risks such as premature mortality (88% of total health benefits), chronic bronchitis (9% of total health benefits) and respiratory ailments (http://www.epa.gov/acidrain).

Since health and environmental benefits from emissions reductions accrue over a long time horizon, as shown in Table 2.2 below, upon completion of Phase II of the SO_2 program, U.S. citizens could expect to reap significant health benefits (on a per capita basis), which substantially exceed the costs (on a per capita basis) on this initiative.

Table 2.2

Ancillary Health and Environmental Benefits and Costs of the U.S. SO_2 Emissions Trading Program in 2010

Effect	Benefits per Affected Capita (1995 US Dollars)
Morbidity	4.09
Mortality	69.25
Aquatic	0.72
Recreational Visibility	3.90
Residential Visibility	6.79
Costs	6.19

Source: Burtraw *et al.* (1998).

Another interesting example where expectations for better health and clean air benefits play a key role, is the global greenhouse gas emissions (GHG) mitigation initiative (often known as the Kyoto Protocol). The goal of this Protocol is to combat climate change and to avoid damages to the stratospheric ozone layer from excessive amounts of GHG (EPA, 1999, and OECD, 1998), which affect all human populations on earth irrespective of location of sources (World Health Organization, 1997). In fact, at the Kyoto Conference of 1997, world nations agreed that GHG emissions should be reduced substantially by the year 2010, compared to the 1990 levels. One interesting observation of the Kyoto Protocol is that it strongly recommends the implementation of a world-wide GHG emissions trading program to achieve its policy target. [30]

Both Canada and the United States are examining the plausibility of implementing trans-boundary emissions trading programs to achieve the Kyoto commitments. It is

[30] For details, see Annex 1 and Title 4 of the Kyoto Protocol.

expected that in the near future, the notion of emissions trading would be extended to a global level in order to deal with the climate change issue. A recent report of the Intergovernmental Panel on Climate Change (IPCC, 1998) reports that Article 17 of the Kyoto Protocol provides for the establishment of an international trading system. In view of the growing interest in emissions trading among the world community, and the critical importance of achieving ancillary health benefits resulting from the reductions in pollutants or from preserving ambient air quality, it seems essential that an evaluation of emissions trading programs take into account the 'value' of the ancillary health benefits that would be realized due to emissions trading. This issue is already being debated in policy circles, since opponents are concerned that international emissions trading would benefit developing countries (at the expense of developed countries), where much of the reduction is expected to occur. This argument is centered on anticipated ancillary health and environmental benefits. [31]

"Hot Spots"

Tradeable permits systems could sometimes lead to localized pollution "hot spots" exceeding ambient air quality standards (Cramton, 2000). One way to remedy this problem is to denominate emissions permits in terms of environmental damage (Revesz, 1996). Even though such denominations may complicate the design of emissions trading programs (Atkinson and Tietenberg, 1982), they may be desirable, or even essential in some situations. For example, such denominations may prove useful in dealing with jurisdictional (i.e., inter-state) issues concerning emissions trading programs, and in conforming to the concept of "environmental justice", i.e., where all of the population is entitled to the same environmental benefits. Recently, New York State was considering a

[31] While we recognize that the accounting for ancillary health benefits as an essential component of the performance appraisal of tradeable permits programs, the undertaking of such a task is beyond the scope of this dissertation.

regulation to penalize local electric utilities who purchase SO_2 permits from the 'dirty' thermoelectric plants located in the Midwestern United States (*New York Times*, May 09, 2000). Even though the goal of this counter-regulation is to prevent the transfer of SO_2 emissions to New York State by prevailing winds, the need for such regulation marks a lapse in the CAAA concerning its provisions for nation-wide SO_2 emissions trading.

2.6 Major North American Emissions Trading Programs

The recognition that emissions trading programs are an effective alternative to address environmental concerns has created an impetus among many countries to experiment with this new instrument. [32] Issues of ambient air quality and water resources are two major areas where this instrument appears to be dominant. [33] The United States has taken the lead in this process, and has already established a number of highly successful programs at both the federal and state levels. In what follows, we consider some highlights of these U.S. programs along with the leading Canadian initiatives (see Table 2.3 below).

As we will see, among all these programs, the U.S. SO_2 tradeable permits program enacted by the CAAA stands out as the most successful story in the history of market-based environmental regulation in the United States. The primary objective of this program is to reduce the country's SO_2 emissions from coal-fuelled electric utilities. This program will be considered in depth as part of the empirical investigation into the *cost* and *efficiency* aspects of emissions trading in Chapters 3 and 4 of the dissertation, which will essentially focus on the U.S. SO_2 program.

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[32] Countries presently considering emissions trading programs include European Union, Norway, Netherlands, Poland, Germany, and France. For a review of non-OECD countries, see Von Amsberg (1995).

[33] For example see, Sieg *et al.* (2000).

Table 2.3

Major Emissions Trading Programs in North America

Country	Program	Traded "Commodity"	Period of Operation	Environmental Objective	Highlights
Canada	Ozone Depleting Substances Permits Trading	CFCs and Methyl compounds	1993 - 96	Counter ozone depletion	Low trading volumes, except among large methyl bromide permits holders.
		Chloroform HCFCs	1996 -		
		Methyl Bromide	1995 -		
Canada	Pilot Emissions Reduction Trading (PERT)	NO_x, VOCs, CO, CO_2, and SO_2	1996 -	Mitigate climate change	This is a pilot program.
Canada	Greenhouse Gas Emissions Reduction Trading (GERT)	CO_2	1997 -	Mitigate climate change	This is a pilot program.
Canada	Greenhouse Emissions Management Consortium (GEMCo)	CO_2	1998 -	Mitigate climate change	A four-year, $2M project to reduce agricultural CO_2 emissions by measuring the uptake of carbon at 200 locations across the Prairies. The project is funded by $0.8M from GEMCo, a matching $0.8M from Agriculture and Agri-Food Canada's Matching Investment Initiative (MII), and $0.4M from Alberta agriculture Food and Rural Development. CO_2 credits are yet to be traded.
United States	Emissions Trading Program	Criteria Air Pollutants under the Clean Air Act	1974 – Present	Reduce excessive emissions of GHG (i.e., mitigate climate change	For new sources of emissions, firms can avoid the usual limits by reducing emissions from existing sources. For existing sources, firms can adjust the level of control applied to the existing sources as long as an aggregate limit is not exceeded.

Country	Program	Traded "Commodity"	Period of Operation	Environmental Objective	Highlights
					Emission reductions beyond allowance requirements can be saved for future trading. *Cost-effectiveness*: Cost savings range from $525 million to over $12 billion US during Phase I. *Drawbacks*: Program not widely used. Uncertainty over future emissions standards and permits' life-span reduced trading.
United States	Lead Phasedown	Rights for lead in gasoline among refineries	1982 - 1987	Reduce dispersion of lead in environment while providing greater flexibility to gasoline refiners.	Rights were determined by the amount of leaded gasoline produced by the firm and the current standard. Refiners were entitled to either earn lead permits, or to obtain lead rights, both in an amount equal to the difference between the actual and allowed quantity of lead Permits could be traded or *banked*. Savings were $250 US million per year, or 20% more than alternative programs *Drawbacks*: Elimination of the banking of lead allowances and the imposition of a lower limit on lead in gasoline.
United States	**SO_2 Emissions Trading Program**	**SO_2 emission reduction credits; mainly among electric utilities.**	**1990 – Present**	**Reduce SO_2 and NO_x emissions by 10M tons and 2M tons tons. (in two Phases)** **Goal: Acid Rain Reduction.**	**This program is the prime focus of this dissertation and an extensive coverage is provided in Table 2.10.**

Country	Program	Traded "Commodity"	Period of Operation	Environmental Objective	Highlights
United States	Lake Dillon Effluent Trading Program	Point and non-point sources of nitrogen and phosphorus	1984 – 1995	Establish a system of property rights for effluent discharges	A cap was imposed on total maximum annual phosphorus load. This regulation allowed *point* sources to receive credit per *non-point* source phosphorus removed. *Cost-effectiveness*: Phosphorus loading reduced by 86%. The promise of trading created an incentive to improve plant operations. *Drawbacks*: Geographical boundaries where permits are traded encircled a limited area.
United States	CFC Trading for Ozone Protection	Production rights for some CFCs, based on ozone depletion potential	1987 – Present	Reduce production of particular CFCs and freeze production and consumption of primary chemical groups thought to lead to ozone depletion	Pemits limit both the production and consumption of CFCs. Substantial reduction in CFCs and other ozone depleting substances has been achieved. However, use and subsequent emissions of HFCs and PFCs as CFC substitutes increased dramatically. The timetable for the phase-out of CFCs was subsequently accelerated, and a tax on CFCs was introduced. *Cost-effectiveness*: Difficult to determine since no studies have estimated cost savings. Relatively low transaction costs associated with trading in the CFC market suggest that the system was relatively cost-effective.
United States	RECLAIM Program	SO_2 & NO_X emissions trading among point sources	1994 – Present	Reduce concentrations of NO_x and SO_2 in Los Angeles area	Policy aimed at larger emitters of ozone-depleting substances.

Country	Program	Traded "Commodity"	Period of Operation	Environmental Objective	Highlights
				to meet federal and state air quality standards.	Annual allocation of permits covering NO_x and SO_2 was ratcheted down each year. Emitters could either use all of their allocated permits or reduce emissions by abatement, freeing up some permits which can be sold or banked, or engage in trading in the market to buy permits from others. Program's requirement of reducing NO_x emissions are likely to be met by 2003. *Cost-effectiveness*: Transaction cost is created due to differences amongst firms, the opportunities to find suitable partners for trading is limited.
United States	BOD Discharges (Fox River) Program	Local biochemical oxygen demand (BOD) discharges trading among point and non-point sources.	1981 – Present	Control BOD dischargers in a 22 mile stretch of the lower Fox River.	Property rights are measured in terms of the *BOD* load and dissolved oxygen in the river at given receptor points. A discharger not able to meet its limit could purchase permits from another discharger. *Cost-effectiveness*: Actual cost savings have been minimal due to the complex administrative requirements and regulations associated with trading. Fox River discharge permits program is lacking most of the features characterizing a sound property rights system.

Sources: Stavins (2000), Hahn (1989), Hahn and Hester (1989a, 1989b), Schemalensee *et al.* (1998), Gangadharan (1997), International Institute for Sustainable Development (1998), Driesen (1998), Ellerman *et al.* (2000), www.epa.gov, www.pert.org, and www.gert.org.

A careful review of these major programs shows that several factors are critical to the success of trading emissions rights. It also provides guidance for policy makers to improve upon the political economy aspects of emissions trading. Considering the relative success of each program (i.e., the lessons learned), a number of critical issues can be summarized.

First, a direct link between emissions limits and environmental goals appears to be critical for ensuring the feasibility of policy objectives. A lesson learned from the Fox River program is that conflicts between discharge limits and water quality targets are responsible for the collapse of the program. Second, it appears that clearly defined trading rules significantly contribute to the success of emissions trading. These rules should clearly identify who the participants and their rights are, and, most importantly, the geographical jurisdictions of the permits market, i.e., national, state, regional, and the like. The Lake Dillon Program is an example where the lack of clearly defined polluter rights has prevented the full use of trading emissions rights.

Other aspect with regard to rules is simplicity, i.e., explicit rules concerning trading, monitoring, and enforcement. Either the absence of clarity, or complexity of the terms governing rules, could render the efforts of the policy maker to achieve certain environmental goals completely futile. A case in point is the Lake Dillon Effluent Trading Program where ambiguities over trading rules have impaired the program's objectives.

To ensure efficient trading of emissions rights, transaction costs must be kept low. The presence of transaction costs deplete the incentive for trading as gains from trade are thin. High transaction costs and several other barriers are often blamed for the demise of the Fox River Program. It is also imperative that trading systems be flexible enough to accommodate new information on environmental consequences, and variable control costs. In fact, flexibility is an essential feature that makes the emissions trading programs simple and easy to work with (Cramton, 2000). For example, the lack of flexibility was evident in both the Lake Dillon and the Fox River Programs, which eventually contributed to a very low volume of trading.

2.7 U.S. SO_2 Emissions Trading Program: A Primer

The passage of the CAAA marked the introduction of the first grand scale tradeable permits program in the United States, namely the *SO_2 emissions trading program.* The main thrust of the CAAA was to reduce the country's sulfur dioxide (SO_2) emissions from coal-fuelled electric utilities, the prime precursor of acid rain. When the new provisions were introduced, these utilities were responsible for over two thirds of the country's SO_2 emissions from *point* sources, while representing only 1,000 of the 18,000 or so known sources (Rico, 1995, p.118).

The approach to emissions reductions embodied in the CAAA is straightforward. An annual 'cap' on permissible national SO_2 emissions generated by coal-fuelled electric utilities is specified. The cap corresponds to the number of emissions permits issued to 'sources' by EPA for that year to 'sources', i.e., to electric plants, in order to cover their emissions. A source carrying a permit is entitled to emit one ton of SO_2, thus limiting the total emissions to the number of permits in possession. Permits 'possessed' by a source are those allocated by EPA, as well as those purchased from other sources. By the same token, if emissions fall short of permits in possession, then the excess permits can be sold in the market, or can be 'banked' for future use. Alternatively, a source may decide to abate emissions below permissible levels, for example, by adopting new technologies or by installing scrubbers. In such cases, the sources can sell their additional permits to other firms. This is an attractive feature of emissions trading, where flexibility in compliance strategies offers sources the freedom to make choices, so that the overall cost of reducing emissions is achieved at the lowest possible cost.

The CAAA authorized the implementation of the SO_2 tradeable permits program in two phases, namely *Phase I* and *Phase II.* Phase I was made operational during the period 1995–1999, and Phase II was to follow Phase I. As shown in Table 2.4, the target of Phase

I was the 263 most SO_2-emissions intensive power generating units at 111 plants operated by 61 utilities, located largely east of the Mississippi River.

Table 2.4

SO_2 Emissions Trading Program: Policy Targets

Phase	Period	Plant Size	SO_2 Emissions Intensity	Reduction Target	Number of Plants
I	1995 – 1999	> 100 MW	> 2.5 lb/mmBtu *	3.5 million tons	111
II	2000 onwards	> 25 MW	> 1.2 lb/mmBtu *	5.0 million tons	1000

* mmBtu: millions of British thermal units. *Sources*: Lee (1991), Kete (1992)

However, as shown in Table 2.5 (see next page), a large number of other units which were targeted by Phase I have also opted-in, augmenting the total of generating units honoring Phase I to 445. Each year during Phase I, EPA allocated each affected source a specified number of permits related to its share of heat input (i.e., emission intensities as shown in Table 2.4) during the baseline period (1985-87), plus bonus permits available under special provisions. Effective in 1996, affected sources were allocated a number of permits based on their 1980 output.

The expected aggregate SO_2 emissions reduction was about 5.7 million tons per year during the period 1995-1999 (Joskow *et al.*, 1998, page 670). However, as shown in Table 2.5, the SO_2 permits trading program has been able to achieve over 50% reduction in emissions during Phase I, i.e., the utilities had emitted 10.68 million tons in 1985, which has been reduced to 5.30 million tons by 1995, or 3.4 million tons lower than the 1995 cap. This achievement is largely due to a substantial over-compliance by the sources. It is interesting to note that some 182 units have volunteered to comply with the Phase I requirements, which explains a major portion of over-compliance during Phase I. As part of the voluntary compliance, the utilities have bought some 1.33 million tradeable permits, boosting the trading activity in the emissions market.

Table 2.5

SO_2 Emissions Trading Program: Phase I Statistics

Variables	Table A Units [1]	Substitution Units [2]	Total Phase I
Number of units	263	182	445
MW capacity	88007	41643	129650
Coal fired units	257	154	411
Pre-1990 scrubbers	1	25	26
Title IV scrubbers	26	0	26
Retired units	7	6	13
SO_2 emissions (million tons)			
1985	9.3	1.38	10.68
1993	7.58	0.97	8.55
1995	4.45	0.85	5.30
Average SO_2 rate (#/millions of British thermal units (Btu))			
1985	4.24	1.58	3.48
1993	3.30	1.67	2.63
1995	2.10	1.21	1.74
1995 permits (millions)	7.22	1.33	8.55

1. Utilities mandated to participate in Phase I
2. Units that voluntary opted-in to Phase I

Sources: Ellerman *et al.* (1999), EPA (1999)

A robust market of SO_2 permits trading has emerged, resulting in cost savings amounting to hundreds of millions of dollars annually, compared to the costs of conventional command and control approaches (Ellerman *et al.*, 2000). Although the program had low levels of trading in its early years, trading levels increased significantly over time (Burtraw, 1996 and Schmalensee *et al.*, 1998). As shown in Table 2.6 below, the sales of permits in 1998 are roughly thirteen times higher than they were in 1993. A overwhelming majority of these permits were exchanged through private transactions, as compared to EPA auctions.

Table 2.6

SO_2 Program: Permits Sales 1993 – 1998

	Permits Sold in EPA Auctions	Permits Sold in the Private Market	Total Permits Sales
Through March 1993	150,010	130,000	280,010
April 1993 – March 1994	176,200	226,384	402,584
April 1994 – March 1995	176,400	1,466,996	1,643,396
April 1995 – March 1996	275,000	4,917,560	5,292,560
April 1996 – March 1997	300,000	5,105,924	5,405,924
Total	1,077,610	11,846,864	12,924,474

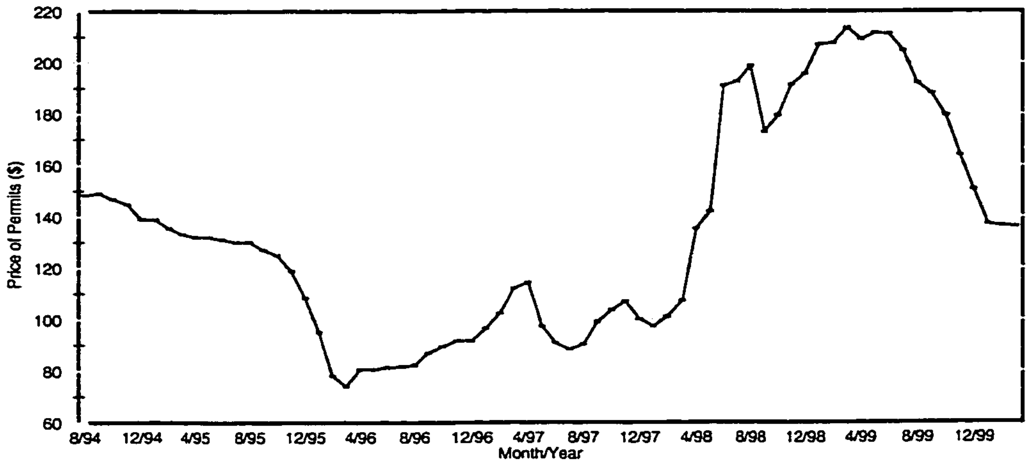
Source: EPA Allowance Tracking System (http://www.epa.gov).

Concerns have been expressed that government regulators may tend to protect their local coal industries and that permits trading would be influenced by large coal producers as Phase II of the SO_2 program progresses (similar to the 'bundling behaviour' of coal producers as described in Doucet *et al.*, 1997). Furthermore, economists have shown that cost-recovery rules of state public utility commissions provide poor guidance for compliance activities (Bohi & Burtraw, 1992, and Bohi, 1994). On the other hand, information on the prices of pemits is difficult to obtain, due to the private nature of many of the transactions. At the annual permits auctions which were set up to help utilities purchase emissions permits quickly, prices have fallen steadily since 1994. [34]

[34] A Table containing average monthly prices of SO_2 emissions permits from the auctions is presented in Table 2 of Appendix 2.

Figure 2.4

SO_2 Program: Permits Prices August, 1994 – March, 2000



* Average Price is the mean prices published by three brokerage firms, namely Emissions Exchange, Cantor Fitzgerald EBS, Fieldston Publications.
Source: U.S. Environmental Protection Agency (http://www.epa.gov)

As shown in Figure 2.4 above, in March 1997, for instance, the clearing price of permits on the *spot* market auction, which was $76, exceeded $140 by September, 1994. The price peaked in April 1999 at $210, and has been declining since then. By March, 2000 it had fallen again to $135. The major factor driving these substantially lower than predicted prices has been over-compliance, particularly in the early years of the regulation. Abatement activity through scrubbers (see Table 2.7 below), U.S. rail-rate deregulation, and contractual commitments to purchase low-sulfur coal from suppliers are responsible for this over-compliance (Ellerman *et al.*, 1999 and 2000). The reason for higher prices recorded during 1999 (including the peak price in recorded in April, 1999) is that utilities were demanding more permits prior to the end of Phase I to hoard (or bank) them for use during Phase II when the missions caps were going to be tightened. Furthermore, Figure 2.4 shows that permits prices fell below 1998 prices by December 1999, the time Phase II of the SO_2 program went into effect.

Another attractive feature of the SO_2 program, which helps the program to stand out among other tradeable property rights regimes, is the lower number of restrictions placed on permits trading (Bernstein and Farrell, 1994). For example, plant or individual purchases or sales of permits did not require EPA's approval. Each state monitors its own trading activity, and state-wide emissions continued to conform to the overall standards previously set by EPA. Flexibility of the SO_2 program was further enhanced by not subjecting private trading to EPA monitoring.

Table 2.7

SO_2 Program: Details of Phase I Reductions

Methods/Regions	Tons of SO_2 Removed (10^3)	Percentage of Total
Total by Installing Scrubbers	1,754	45.1
• New CAAA Scrubbers	1,734	44.6
• Other Scrubbers	21	0.5
Total by Fuel Switching	2,133	54.9
• North Appalachia	205	5.3
• Central Appalachia	756	19.5
• South Appalachia	60	1.5
• Midwestern	406	10.4
• Powder River Basin	518	13.3
• Other Western Coal	146	3.8
• Imported Coal	22	0.6
• Natural Gas	20	0.5
Total	3,888	100.0

Source: Ellerman *et al.* (1999).

Even though this means that it is difficult to obtain a precise measure of the amount of trading that had taken place in this market, EPA continues to adopt a *laissez-faire* approach towards the trading of permits used by utilities to comply with the policy each year. This effort by the EPA provides some information regarding the level of trading activity. Since

March 1994, more than 2,000 permit transactions, involving over 40 million allowances, have been recorded by EPA. Nearly 90% of participating utilities have been involved in some kind of private allowance transfer (http://www.epa.gov).

As shown in Table 2.8, methods of compliance and the corresponding average costs have varied substantially during Phase I of the SO_2 permits programs. Despite the average cost of scrubbing, which is about 73% higher than that of fuel-switching, 45% of the participating utilities have chosen scrubbing as a chief means of compliance.

Table 2.8

SO_2 Program: Phase I Cost of Compliance

Method	SO_2 Reduction (10^3 tons)	Total Cost of Compliance (1995 $)			Average Cost ($/$SO_2$ ton)
		Fixed	Variable	Total	
Scrubbing	1754	375.0	89.3	464.4	265
Fuel-switching	1709	57.2	204.1	261.3	153
Other	425	0	0	0	0
Total	3888	432.2	293.5	725.7	100.0

Source: Ellerman *et al.* (1999).

Another important observation to note is the higher fixed cost and lower variable cost per ton of SO_2 reduction associated with scrubbing, as compared to fuel-switching. It has been argued that the potential for scrubbers to last longer, allowing initial capital cost to be spread over more tons of SO_2 reductions, has reduced the cost difference between scrubbers and fuel-switching. Phase II of the U.S. SO_2 program which started in January, 2000, further tightened the emissions cap, covering *all* electric generating units in the United States. Effective in 2000, the EPA will issue *nine million* permits annually. During Phase II, certain utilities are expected to be compensated for potential restrictions on growth, and others, which already meet or exceed the requirements, will also be rewarded.

As shown in Table 2.9 below, studies completed so far provide substantially different estimates on cost-per-ton reductions during Phase II. According to these estimates, marginal costs of abatement are expected to vary between $291/ton to $760/ton. If these numbers were compared with Phase I permit prices, emissions reductions in Phase II appear to be costlier on a per unit basis, unless further improvements in power generation technology would drive down marginal costs. This may not seem totally unexpected, since Phase II calls for tighter standards which will require significant technological improvements, because most low cost options, such as the installation of scrubbers have already been exploited during Phase 1. In other words, the greater the reductions in emissions the higher the per unit cost of reduction.

Table 2.9

SO_2 Program: Cost Estimates of Phase II (2010)

Study	Annual cost (1995 $ billion)	Marginal Cost per ton SO_2 (1995 $)	Average Cost per ton SO_2 (1995 $)
Carlson *et al.* (1998)	1.1	291	174
Burtraw *et al.* (1998)	0.9	---	239
White (1997) [EPRI]	---	436	---
ICF (1995) [EPA]	2.3	532	252
White *et al.* (1995) [EPRI]	2.4 – 2.9	543	286 –334
GAO (1994)	2.2 –3.3	---	230-374
Van Horn Consulting *et al.* (1993) [EPRI]	2.3 –5.9	520	314 –405
ICF (1990) [EPA]	---	579 – 760	348 –499

Source: Burtraw (1999).

During Phase II of the program, an additional 900 electric utilities with a net capacity of 25MW or greater will be added to the Phase I group of the 111 utilities emitting the highest amounts of SO_2. This means that Phase II would cover virtually all coal-burning electric utilities in the United States. The goal of Phase II is to reduce SO_2 emissions by an additional five million tons by the year 2010. If trading permits represent the carrot of the system, its stick is a penalty of $2,000 per ton of emissions that exceed any year's permits, in addition to a requirement that such excesses be offset in the following year (Stavins, 1998a and 1998b).

2.8 Tabular Summary of the Analytical Framework

Having discussed the significance of a wide array of economic, political, and social factors in the evaluation of market-based environmental policies, and having developed a formal process incorporating different stages of policy formulation, a summary of the analytical framework presented in Section 2.5 can now be provided. Focussing on the U.S. SO_2 program, efforts will be made to (a) identify numerous aspects of this program in terms of the components of the framework, and (b) demonstrate the significance of these components in an overall evaluation of the market-based environmental policies. Table 2.10 presents the highlights of this evaluation based on the proposed framework.

Table 2.10

An Evaluation of the U.S. SO_2 Program Using the Analytical Framework

ELEMENT		SIGNIFICANCE
POLICY TARGET	• **Institutional Structure**	Played an extremely important role in setting the *terms* of the policy target of the SO_2 permits program. For example, in the 1980s, there were more than 70 laws governing numerous regulation directed to the problem of acid rain.
	Legislature	U.S. Congress had intense debates over the actual distribution rules of SO_2 permits. State representatives tried to obtain the maximum benefits of this process for their constituents. Indiana and Ohio states, where cost of electricity was predicted to go up, demanded a cost-sharing with the other states.
	Bureaucracy	Since bureaucrats are eager to see their views accommodated in policies, they do not favour decentralized policies such as emissions trading, because such instruments do not require the use of their technical expertise. So implementation of the SO_2 program was seen as taking their responsibilities away. In turn, the need for an agency like EPA arose both to accommodate the SO_2 program, and to eliminate state prerogatives for imposing environmental regulation.
	• **Regulatory Structure**	The regulatory structure governing U.S. environmental standards played a key role in setting the goals for both Phases of the SO_2 program. See below.
	• **Environmental Standards and Practices**	*Phase I*: 1980 SO_2 emissions were to be cut in half by the year 2000. 110 plants with emissions intensities of 2.5lb/mmBtu or more were targeted. *Phase II*: From January, 2000, all coal-fuelled electric power plants with emissions intensities of 1.2lb/mmBtu or above will be targeted. Technology-based standards, namely Lowest Achievable Emissions Rate (LAER), Best Available Control Technology (BACT), and Reasonably Available Control Technology (RACT) were used as baselines for the choice of targets of the SO_2 program.
	• **Interest Groups**	At the outset, strong resistance/criticism prevailed, as permits were viewed as a '*license to pollute*'. At a later stage some influential green activists such as the Environmental Defence Fund (EDF)) openly supported the SO_2 initiative. The United Mine Workers Union opposed the implementation of the SO_2 program, fearing that it would create incentives for a higher use of low-sulfur coal (which it did), produced largely in non-unionized mines in Wyoming's Powder River Basis, as opposed to high-sulfur coal produced in unionized eastern mines.

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	ELEMENT	SIGNIFICANCE
INSTRUMENT CHOICE	• **Political Aspects**	Political factors played a significant role in the design of 'rules' concerning the issues of equity and choice of permit features. See below.
	Equity Issues	The argument by Indiana and Ohio to share costs with the other states, resulted in an implicit subsidy for the dirtiest utilities located in the Midwest. These utilities were grand-fathered SO_2 permits effective in 1995, whereas cleaner utilities were grand-fathered in January, 2000. So, the implicit subsidy is the value of the five years' (1995 to 2000) extra permits, whereby the dirtiest utilities can sell their permits to any other utility, including a cleaner plant.
	Initial Allocation of Permits	Grand-fathered initial permits on the basis of average fuel-input during 1985–1987. Since the distribution was based on 'fuel-input' rather than historical emissions, utilities which invested in green technologies, were not penalized by allocating fewer permits. Changes in fuel usage by plants were averaged over the three year period 1985–1987. These three years were chosen as no evidence of a recession existed during this period.
	Revenue Recycling	Midwestern states such as Indiana and Ohio were offered an implicit subsidy geared to recover increased cost. This allowed a five year (1995 to 2000) 'amnesty' for the dirtiest utilities. Effective January, 2000, a quarter million permits, or 2.8% annually of the total are kept as a Special Allowance Reserve (SAR), whose price is fixed at $1,500, and indexed to inflation. End of year left-overs are sold at auctions. These auctions are revenue-neutral as 2% of the sales revenue is redistributed.
	• **Institutional Aspects**	The SO_2 program is characterized by a high degree of dependence on various institutional aspects of the design of allocation rules and revenue redistribution as described below.
	Price vs. Quantity Debate	The political unfeasibility of imposing taxes (a price instrument) and the increasing cost burden with the command-and-control type of regulation opened up the debate over the appropriateness of a mix of price and quantity elements, which gave rise to a '*safety valve*' as described below.
	Emissions Caps / Standards	The *caps* placed on permissible limits of emissions (i.e.,, three and half million tons a year during Phase I, and 5 million tons a year during Phase II are consistent with the U.S. technology-based standards (LAER, BACT, RACT).

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	ELEMENT	SIGNIFICANCE
I N S T R U M E N T C H O I C E	Hybrid / Safety Valve	Both to encourage trading and to prevent excessively high prices of permits, (thus to avoid permit 'market failures'), a '*safety valve*' mechanism was built into the SO_2 program. The U.S. congress established a reserve pool where 3% of the total permit quota was withheld to ensure access to permits by new utilities. This pool is sold at a predetermined price ($1,500 or twice the market equilibrium price) or is auctioned by EPA. Any left-over permits from the pool are sold at auction to the highest bidders.
	• **Product Market Characteristics**	The electricity market is the major *product* market, and the coal (and oil and gas markets, to some extent) the major *input* market feeding the SO_2 program.
	Demand and Supply Conditions	The coal share of electricity generation is falling. A high degree of substitution of low-sulfur coal for high-sulfur coal has taken place in Phase I and is expected to continue during Phase II. Shifts in demands for coal (based on the sulfur content), changes in production and demands for other fuels, and consumer preferences for alternative sources of power generation (in line with environmental objectives) have changed the market conditions. These conditions have affected the performance of the SO_2 program in Phase I, and will continue to affect it during Phase II as well. Discussion in the text contains details of specific effects.
	Pre-Existing Market Distortions	The electricity industry had been subjected to a number of other regulatory provisions including taxes and price ceilings (both federal and state) when the CAAA were enacted through the SO_2 permits program. (For details, see the Federal Energy Regulatory Commission Annual Reports). These distortions are apparently driving a wedge between the 'achieved' cost economies (40% reduction over command and control regulation) and the 'potential' cost economies (70% reduction over command and control regulation) of the SO_2 permits program.

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	ELEMENT	SIGNIFICANCE
PERFORMANCE APPRAISAL	• **Cost Effectiveness**	Actual cost savings are about 40% lower as compared to command and control regulation, and the potential for savings is as high as 70%. Increasing competitiveness in the U.S. electricity market (as well as in the Canadian exports market) has created pressure to further reduce costs, which also contributed to further cost savings. While the estimated cost savings in the literature range from over one billion to only 300,000 dollars a year, the latest conservative estimates indicate that the cost savings attributable to Phase I of the U.S. SO_2 trading program were between $225 and $375 million. Permits were ratcheted down each year; and very few restrictions were placed on trades. Permits prices have varied substantially, but the actual prices have been much lower than many studies had predicted. Highest actual price per permit recorded so far is $ 212 (May, 1999) and the lowest is $ 74 (March, 1996). During the last few months of 1999, when Phase I was coming to an end, permit prices appeared to have been increased by utilities' demand for extra permits to cover emissions during Phase II, which started in January, 2000.
	• **Efficiency Gains / Technological Innovations**	Market prices have declined substantially due to innovative activity undertaken in the wake of the SO_2 program. Low-sulfur coal has emerged as a major low-cost means of compliance. Productivity increases in surface coal mining led to a 45% decrease in prices of low-sulfur coal during 1993-1998. Settlements of rail transport problems in the Midwest coupled with investments in rail infrastructure and innovative activity, have reduced coal transport costs by as much as 50%. New technologies have emerged to improve the blending of low and high sulfur coal while the cost of scrubbers, a favourite option for compliance, fell by about 50% in the early 1990s.
	• **Property Rights Characteristics**	Overall, a very well designed property rights scheme has emerged from the SO_2 emissions trading program, and the critical characteristics of property rights, as listed below, appear to have been secured and are in-tact in this system. However, the failure to recognize the SO_2 permits as property rights by the CAAA has concerned some economists as to whether this would lead to some uncertainties during Phase II.
	Exclusivity	Apart from the seemingly inappropriate definition of the SO_2 permits by the CAAA, exclusivity property is nicely maintained with regard to other aspects of permits, since the definitions are based on the emissions intensities of utilities, as categorized under Phase I and Phase II.
	Transferability	SO_2 permits were freely transferable in both private exchange and auctions at the on-going market (or equilibrium) price.

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	ELEMENT	SIGNIFICANCE
PERFORMANCE APPRAISAL	Flexibility	Flexibility is a key feature of the program, which substantially contributed to the success of the experiment. By allowing sources to use a wide array of options to meet the targets, an incentive was created among them to search for the least cost abatement option, an effort which, as discussed above, resulted in productivity gains and technological improvements in power generation.
	Enforceability	High fines and the EPA's Continuous Emissions Monitoring system (CEMS) made it highly unprofitable and virtually impossible to breach the system or to understate emissions. Hence, no need arose for 'compliance' reporting. Violations carried a hefty $2,000/ton penalty in addition to extra emissions reductions in the years following the violation.
	Life-Span	The annual EPA auctions advocate *four* different types of sales. (i) Spot market auction. These permits are usable during the year of auction only. (ii) Seven-Year advance auction: These permits are usable seven years later. For example if the purchase was made in 1993, usage would begin in 2000, after Phase II has started. (iii) Six-year advance auction for seven-year permits: These permits are left-overs of (ii) that are sold one year later. (iv) Private auction: Source to source trading at EPA auctions. The initial permits allocated at the outset of the program are valid during both Phase I and Phase II.
	Transaction Costs	Transaction costs remained low, since utilities report their permit trades directly to EPA, which only verifies aggregate annual volumes of trading. The information on trading volumes and potential market price ranges, along with other market characteristics, is easily available to all utilities. This reduces uncertainty at auctions. The price signals from the yearly SO_2 auctions yield very low transaction costs. For example, brokerage fees lie around 5%, which is substantially lower than the average of other trading permits systems.
	Certainty Criterion	Since SO_2 permits are of high quality (in terms of property rights characteristics) the transaction costs remained low, which contributed to a relatively high degree of certainty. The only concern was the failure of the CAAA to recognize the SO_2 rights as property rights. Some analysts (for example Svendsen, 1998) argue that the gap between the realized cost savings and the potential cost savings may be attributable, at least in part, to uncertainty accompanied by this definition.

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ELEMENT		SIGNIFICANCE
PERFORMANCE APPRAISAL	• **Micro- and Macro-Economic Impacts**	Higher demand for low-sulfur coal increased its production, and lowered high-sulfur production. Some job losses have been recorded. There are other micro concerns with regard to GDP level, employment, inflation, etc. Nevertheless, conflicting (and often biased) views exist in the literature on *cost effects* and *productivity effects*. Chapters 3 and 4 will undertake a formal inquiry into these two important issues.
	• **Ancillary Health / Environmental Benefits**	Substantial reductions in health risks of atmospheric pollutants such as premature mortality (88% of total health benefits) and reductions in chronic bronchitis (9% of total health benefits) and the incidence of respiratory disorders have been achieved (More details are in Table 2.2). Phase I has recorded an astonishing 40% over-compliance that proves useful in early ecological recovery by avoiding further environmental degradation.
	• **Geography / 'Hot Spots'**	The SO_2 Program was designed to avoid the risk of '*hot spots*'. No ambient standards were expected to be violated since (i) acid rain occurs due to emissions concentration (as opposed to the annual level of emissions) in the atmosphere, and because SO_2 emissions were to be reduced by 50% over a ten year period (1990–2000), and (ii) dirtier utilities are located in the West, and their marginal abatement costs are lower than those located in the East, and wind blows from West to East. However, in May 2000, New York legislators were considering laws to prevent Eastern utilities from selling their permits to dirtier utilities in the West, which continue to use these permits and emit large amounts of atmospheric pollutants, which through prevailing wind continue to affect the air quality of the East, New York state in particular (*New York Times, May 09, 2000*).
CONCLUSION		Overall, the U.S. SO_2 emissions trading program is considered a "huge success", which has been categorized as a well-designed and highly efficient program. Phase II just started with the hope of delivering even more exciting results. Low transaction costs greatly contributed to high volumes of, and substantial gains from, permits trading primarily due to cost savings. The SO_2 program will serve as a "model" for future endeavours.

Sources: EPA Allowance Tracking System, Ellerman *et al.* (1999, 2000), Joskow *et al.* (1997), Svendsen (1998), Rico (1995), Reed and Stevens (1993), Kete (1992), Lee (1991), and the author's calculations.

The presentation in Table 2.10 reflects the importance of the elements of the *analytical framework* that was developed in Section 2.4. As shown, the areas of success can be successfully examined in terms of the performance criteria outlined in Figure 2.2. The SO_2 program has been chosen to demonstrate what is envisioned as an overall evaluation of the critical aspects and the virtues of emissions trading programs.

2.9 Canada's Limited Experience with Market-Based Policies, and the Prospects for the Future

Background

The Canadian Environmental Protection Act (CEPA) provides the legislative basis for Canada's regulatory measures designed to protect the environment. CEPA offers a wide range of powers to both federal and provincial government regulators, which allow them to implement all 'necessary' measures required to prevent pollution and preserve the environment. Despite the fact that Canada's southern neighbour, United States, is the largest emitter of all pollutants in North America (also the largest emitter of NAFTA), and the party responsible for Canada's trans-boundary pollution, [35] increasing amounts of emissions (as shown in Table 2.11), particularly SO_2 [36] , CO_2, NO_X and VOCs, being generated by Canada's industrial activity have posed a challenge for Canadian policy makers in recent years.

Table 2.11

Major Pollutants in Canada (in Kilo tons)

Pollutant	1990	2000 *	2010 *
SO_2	3305	2802	2867
NO_X	2106	2080	2187
VOCs	2829	2682	2915

*National Air Issues Coordinating Committee (NAICC) Forecast
Source: http://www.ec.gc.ca

[35] For example, more than half of the acid rain (SO_2 and NO_X) in eastern Canada comes from the United States (http://www.ec.gc.ca).

[36] According to the latest regulation of the Government of Ontario, Ontario Hydro, the largest single emitter of SO_2 and NO_X in eastern Canada, must reduce its SO_2 emissions to 157,000 tons by the year 2001 (http://www.ontariopowergereation.com).

This situation received wider attention after a very recent NAFTA report has rated Ontario as the *third* largest polluted region in North America. [37] As a remedy, the Government of Canada, in compliance with the Canada-United States Air Quality Agreement, stipulated that seven eastern-most provinces must reduce their total SO_2 emissions [38] to 2.3 million tons from 1994 onwards. Furthermore, a permanent national cap was introduced in 2000 to limit SO_2 emissions to 3.2 million tons a year. [39] Positive responses have already emerged. With regard to combating acid rain (reducing SO_2 and NO_X emissions), Canada appears to have made remarkable progress towards the latter part of the nineties due to proactive efforts by governments and industry to change industrial processes, to invest in abatement, and to switch fuel sources. Consequently, SO_2 emissions in eastern Canada fell by about 56% between 1980 and 1994. [40]

Canada's Experience with Emissions Trading

Canada is no exception when it comes to applications of market-based instruments for environmental protection. As in many other countries, regardless of the known inefficiencies of the traditional 'command and control' approaches, Canadian policy makers, up until the late 1980s, had largely disregarded market-based instruments. As a result, Canada's experience with market-based instruments to date has been limited to a handful of initiatives.

The Acid Rain Control Program of 1985 was the first federal program implemented to reduce the country's SO_2 emissions from industrial sources. The program required a uniform level of reductions in SO_2 emissions throughout all regions of Canada. Ontario Hydro

[37] The information comes from the Commission for Environmental Co-operation, an arm of NAFTA that compares pollution statistics from Canada, the U.S. and Mexico. The latest report was issued on May 31, 2000 and is based on emissions data from 1997. Also, see National Economic Research Associates (1993).

[38] In Canada, about 18% of electricity is generated by coal combustion, as compared to of 50% in the neigbouring United States.

[39] For details, visit http://www.ec.gc.ca.

[40] Details are in Environment Canada website: http://www.ec.gc.ca

dominated limited trading of emissions credits. The Canadian Council of Ministers of the Environment (CCME) program is another joint federal-provincial initiative implemented in two phases beginning in 1988. Phase I was geared to reduce NO_X emissions in Canada for a five year period from 1995 through 2000, and Phase II was designed to control volatile organic compounds (VOC) emissions for an extended five year period from 2000 through 2005. In 1988, Environment Canada introduced another program to reduce ozone-depleting substances such as CFCs. Under this program, the production and importation of CFCs and methyl chloroform were banned, and firms using these substances received transferable permits equivalent their consumption of these chemicals in 1993, which were transferable. However, only a handful of transactions took place during the period (Haites, 1996). In 1995, Canada distributed tradeable permits for methyl bromide directly to Canada's 133 users of the substance. Some trades took place among large players. Canada has also operated a limited HCFC permits scheme since 1996, trying to assure firm compliance towards the limits specified by the Montreal Protocol.

More recently, federal policy makers introduced two Pilot programs, namely the Pilot Emissions Reduction Trading (PERT) (led by Ontario) and Greenhouse Gas Emissions Reduction Trading (GERT) (led by British Columbia). Both initiatives include *credit* and *banking* as fundamental elements of the programs. The PERT, introduced in 1996, has encouraged emitters in Ontario to voluntarily report industrial emissions reductions beyond the regulated limits or any achievements through voluntary action. Registered credits of PERT are transferable between emitters; the pollutants covered include NO_x, VOC, CO_2, SO_2 and CO. The GERT project introduced in 1997 was ended in December 1999. It covered six Canadian provinces, namely Alberta, British Columbia, Manitoba, Nova Scotia, Saskatchewan and Quebec. Government administrators reserved the right to tighten emissions reductions specified under GERT. Trading under the GERT required either the buyer or the seller of credits to be Canadian, and, until 1999, only five trades were recorded (http://www.pert.org and http://www.gert.org). At the provincial level, in Ontario and New Brunswick, some electric utilities were allowed to make inter-plant trades of emissions, provided that the total allowable emissions were not exceeded.

The Greenhouse Emissions Management Consortium (GEMCo) is another Canadian initiative to develop market-based approaches to reduce greenhouse gases. GEMCo was established in 1996 by Canadian energy and hydro companies [41] with a view to reduce agricultural CO_2 emissions and/or to increase agricultural carbon storage, and thereby to assist Canada's efforts to meet its Kyoto Commitments. The four-year, $2M project involves measuring the uptake of carbon at 200 locations located across the Prairies. The project is funded with $0.8M from GEMCo, $0.8M from Agriculture and Agri-Food Canada and $0.4M from Alberta Agriculture Food and Rural Development. Recent estimates suggest that as much as 14 million tons of CO_2 or more can be stored in agricultural soils in Canada every year for the next 20 years. Trading of CO_2 credits is yet to be introduced.

Future Prospects

In recent years, Canadian policy makers have shown a keen interest in market-based instruments, particularly emissions trading programs, to deal with pressing environmental concerns. The cost savings and efficiency gains of similar programs in the United States (notably, the SO_2 permits program), and the failure of the traditional command and control regulation to reach anticipated environmental goals, appear to have significantly contributed to this new impetus towards market-based instruments. As the deadline is fast

[41] GEMCo members include B.C. Hydro, Canadian Utilities Ltd. (including Alberta Power, Northwestern Utilities Ltd., and CU Power International), EPCOR, Nova Gas Transmission, Nova Scotia Power, Ontario Hydro, SaskPower, TransAlta Corporation, and the Westcoast Energy Group of Companies (including Centra Gas BC, Alberta and Manitoba, Northeast Pipelines, Pacific Northern Gas, BC, Union/Centra Gas, Ontario, Westcoast Energy Inc., Westcoast International, and Westcoast Power Inc. which own and operate over 80% of natural gas transmission and distribution infrastructure, over 90% of independent power production capacity, and over 50% of electricity generating plant, including the largest coal producer and four largest generators of coal-based electricity in Canada.

approaching for Canada to meet its commitments to reduce greenhouse gas emissions by 6% below 1990 levels, as agreed upon at the Kyoto Convention in 1997 (approximately 26% below 1999 levels), debates on the feasibility of a nation-wide emissions trading program are presently high on the agenda in both political and academic circles.

A number of Canada-wide research projects have already been initiated to explore future possibilities for drafting emissions trading programs to address Canada's environmental concerns, both domestically and internationally. One such comprehensive study is that of the National Round Table on Environment and Economy, a collaborative effort among several federal and provincial government departments (Institute for Research on Environment and Economy, 1999). In addition, a number of economic fora and workshops have been organized to exchange information among experts of market-based environmental policies,public policy makers, and legal advisors responsible for the implementation of such programs in Canada (Environment Canada / Health Canada, 1999).

Recently, the federal government appointed sixteen stakeholders' panels (known as Issue Tables) to examine the potential for greenhouse gas mitigation in Canada. This initiative is part of the implementation of Canada's commitments to the Kyoto Protocol, which recommended, among other things, the implementation of a global emissions trading program to reduce global greenhouse gas emissions. An expert group called the Tradeable Permits Working Group (TPWG) has just completed preliminary work concerning the possibility for implementing a Canada-wide emissions trading program. The TPWG predicts that emissions trading, particularly among electric power plants, would entail significant cost savings. It would also be easy to monitor the required reductions in greenhouse gas emissions through to 2010 (TPWG, Options Report, 2000). Responding to this federal initiative, TransAlta, one of the largest multinational electric companies based in western Canada, has joined hands with a leading German electric company, Hamburgische Electricitats-Werke AG (HEW) to trade emissions reduction credits amounting to 24,000 tons of CO_2 (equivalent to 3,000 cars) (Press Release, June 16, 2000, http://www.transalta.com).

Given the limited experience with emissions trading programs, and the increasing popularity of, and the need for, market-based instruments, Canada can benefit immensely from the large-scale and highly successful U.S. emissions trading programs. In this regard, the U.S. SO_2 program will serve as a 'model' or a 'toolkit' for Canadian policy makers, whose objective is to address Canada's pressing environmental needs through cost-effective and economically-sound means.

2.10 Concluding Remarks

This study presents the elements of a political economy analytical framework in market-based environmental policy formulation. By defining 'environmental policy' as a process involving *three* stages, namely the policy target, instrument choice and performance appraisal, the study developed an *analytical framework* primarily within the realms of positive economic theory. The goal of this framework is to provide a logical basis for the evaluation of market-based environmental policies.

The major emphasis of this study was an examination of the U.S. SO_2 emissions trading program made possible by the CAAA. While we touched on all of the major North American emissions trading programs, we illustrated the significance of our analytical framework by applying it to the highly celebrated U.S. SO_2 program. The emphasis on the U.S. SO_2 emissions trading program helped us assess the criteria considered essential in the analytical framework. Our discussion of the promising features of emissions trading programs suggested the applicability of this instrument in a wide variety of cases, where market-based actions are warranted to address pressing issues of environmental / ecological degradation.

Given the conflicting views in the current literature as to which criteria should be used (and which are the most important) in evaluations of tradeable permits programs, the proposed *analytical framework* should serve as a vehicle for unifying these different perspectives. This framework has stressed the need for a *simultaneous* consideration of issues of political economy before passing judgments on the relative merits of tradeable permits systems, specially those listed in Figure 2.2.

The main objectives of this Chapter has been two-fold. First, our task was to set the stage for the empirical analysis in chapters 3 and 4 of the dissertation. These forthcoming two Chapters will undertake a comprehensive inquiry into cost effectiveness and technological innovation attributable to the passage of the U.S. SO_2 emissions trading program. Specifically, the two chapters will develop appropriate methodologies to determine empirically the significance of cost savings and efficiency gains of the program. A data set representing sixty eight of the largest electric utilities operating in the United States will be used to test the implications of the models.

Second, the objective was to explore all potential dimensions of market based policies which are geared to achieve environmental goals. Focussing on the political economy view point, we tried to understand the important determinants of the success of tradeable emissions programs. The existing gaps in the literature concerning performance appraisal of market based policies was the motivation for this undertaking. Being aware of the increasing interest in the on-going initiatives for tradeable permits programs in Canada, the latter part of the discussion was devoted to elaborate on the important lessons from the large scale applications of the emissions trading programs of the United States.

It is believed that this study will be fruitful in providing insights for Canadian policy makers with the design of appropriate market-based policies to deal with environmental issues at home similar to the ones in the United States. Our focus on the U.S. SO_2 emissions trading program should serve as a reference, both in terms of the design and evaluation of future market-based policy initiatives. Given the close proximity of the United States and the increasing debates over trans-boundary emissions between the two countries, we believe that the lessons from the U.S. SO_2 program, should prove particularly relevant for Canadian policy makers in meeting international commitments such as those of the Kyoto Protocol.

While the two important elements of the performance appraisal, namely cost effectiveness and efficiency gains, as identified in the analytical framework will be carried forward for further methodological inquiry in Chapters 3 and 4, empirical analysis of the other important elements is beyond the scope of this dissertation. Nonetheless, it may be an important area for future research which would help obtain an even richer set of insights into the actual interactions of these elements in the setting of environmental policy.

AN ECONOMETRIC ANALYSIS OF MARKET BASED ENVIRONMENTAL REGULATION: THE CASE OF ELECTRIC UTILITIES 3

*"It can be predicted with all security that in fifty years **light** will cost one fiftieth of its present price, and in all the big cities there will be no such thing as night."*

J. B. S. Haldane
British Scientist, 1927.

JEL Classification: C33; C51; D21; L51; Q28

3.1 Introduction

The oil crises in the 1970's led to a major restructuring of the United States' energy policy, with new laws being enacted to reduce its dependence on imported oil by encouraging a greater use of coal for electric power generation. Although the country is endowed with 31% of the world's recoverable reserves of coal, and coal accounts for more than 85% of potential U. S. fossil-fuel reserves, the combustion of coal furnishes only about 50% of the country's electricity, while oil and gas together provide some 26%. [1] Although the use of coal resources has risen substantially in recent years, further opportunities to exploit these reserves still exist.

The increasing amounts of coal being burnt by electric utilities appear to be a major factor responsible for the continuing environmental degradation in the country, as the use of coal contributes to the causes of acid rain and global warming. Latest statistics reveal that burning of coal contributes about 70% of the SO_2, 30% of the NO_x, and 35% of the CO_2 of the country's total emissions from all sources of air pollution.[2] Thus, coal-fuelled electric plants are considered one of the leading causes of pollution in the United States.

[1] U.S. Department of Energy, Annual Report- 1997 & Scientific American, 1991.
[2] National Air Quality and Emissions Trends Report (http://www.epa.gov).

In order to cope with the problem, the U. S. government introduced several Amendments to the Clean Air Act in 1990 (hereafter, the CAAA), setting more stringent standards on permissible emission levels for combustion of coal by electric utilities. The CAAA authorized the *Environmental Protection Agency* (EPA) [3] to launch a nation-wide program [4] to reduce air pollution, primarily by overseeing the production activities of the coal-fueled electric utilities in the country. The salient feature of the program was the creation of a market for trading emission rights for the first time in the U.S. history. The concept of *emissions trading* [5] is an economic, incentive-based alternative to command-and-control regulation which is designed to achieve pre-specified environmental targets with minimum costs. Under this scheme, utilities exceeding the set emission limits have other options to comply with the CAAA, such as investing in abatement capital, improving existing technology, inventing new environmentally friendly technologies, fuel-switching, or adjusting the output, i.e., *net* generation of power. [6]

Since their inception, the CAAA have led to a substantial restructuring in power generating plants. The affected utilities were attempting to accommodate the new environmental measures through various means of compliance. The recent findings reveal that such restructuring has come about at a social cost, notwithstanding its social benefits (Carlson *et al.*, 1998). Nonetheless, "green" activists representing environmental lobby groups argue that the CAAA were indeed an essential move on the part of the federal

[3] The EPA was established as part of an earlier set of Amendments to the U.S. Clean Air Act in 1970.

[4] The program is implemented in two stages, namely Phase I (started in 1995), and Phase II (started in January, 2000). 110 utilities have been affected by the Phase I. See Appendix II for details.

[5] In an emissions trading program, sources of a particular pollutant (for example, the air pollutants under the CAAA) are given tradeable permits to release a specified number of tons of the pollutant. Under the environmental regulatory scheme, the government issues only a limited number of permits consistent with the desired level of emissions. The firms acquiring permits may either keep them and release the pollutants, or reduce their emissions and sell the permits. The fact that the permits have value as an item which may be sold or traded, gives the firm an incentive to reduce its emissions. The analytical framework presented in Figure 2.2 on page 27 (Chapter 2) shows how these incentives are formed in a political economy setting.

[6] Net generation equals total generation of power minus plant's usage.

government. Critics [7] maintain that the new environmental measures are more restrictive than necessary, and that they have adversely affected the electric utility industry in the country (Yaisawarng, *et al.*, 1994).

With these divided opinions among researchers, the regulators, particularly those responsible for the CAAA, have been trying to determine how they should prioritize their agenda: energy policy or environmental policy. While many economists would agree that there is a likely trade-off between the two, a clear-cut answer to such a question is not easy to come by. What is evident though, is the fact that it is essential to have a certain degree of co-ordination and co-operation between the uses of the two policies. Thus, the primary task confronting the economist in choosing the appropriate strategy is to ascertain the economic costs of the CAAA, and to weigh them against the resulting benefits, so that the net social benefit or cost is known prior to passing any judgment on the merits of the CAAA.

However, despite a number of useful studies, the recent literature on this issue still lacks an adequate analysis as to *whether*, *when*, *how*, and to *what extent* the CAAA have affected the electric utility industry in the United States. Thus this chapter proposes to undertake an in-depth inquiry into these questions. The approach taken by this study is essentially an empirical one. A panel data set [8] covering major U. S. electric utilities is used to examine the effectiveness of the CAAA in terms of their economic impact on the U.S. electric utility industry. Since the major emphasis is on the 'cost side', [9] much of the discussion will be based on the findings of an econometric analysis which consists of estimating a cost function and a set of cost-share equations.

The remainder of the paper is organized as follows. Following the introduction, a brief review of the recent literature is presented in Section 3.2. Section 3.3 then discusses the

[7] For a critique of the market-based environmental regulation by a non-economist, see Beder (1994).
[8] A detailed description of the data set and the other constructed series are presented in Appendix I.
[9] The third paper of this dissertation employs the Data Envelopment Analysis (DEA) methodology to analyze efficiency aspects of these utilities.

choice of a cost function with special emphasis on *shadow* input prices. Section 3.4 outlines the econometric model. Section 3.5 constructs the testable hypotheses, and Section 3.6 provides a summary of the data used in the analysis. Estimated coefficients of the model are presented in Section 3.7, which is followed by an economic interpretation of results in Section 3.8. Section 3.9 concludes the study with a summary of the key findings.

3.2 Review of the Recent Literature

A large body of literature deals with the firms' cost minimization problem under different types of *regulatory constraints*. However, a majority of these previous studies have focused on the *rate of return* (*ROR*) regulation, [10] while a handful of them examine the problem under environmental regulation. Furthermore, with very few exceptions (e.g., Atkinson & Halvorsen, 1984 and 1998), these studies model the problem within a neo-classical framework, where firms are assumed to be operating under perfectly competitive market conditions. However, it should be noted that the regulated firms, regardless of the type of regulation to which they are subject, fail to achieve cost-minimizing outcomes in production (Averch & Johnson, 1962, Davis, 1973 and Goulder & Parry, 1999). Thus, the assumption of perfectly competitive market conditions is not suitable for analyzing the regulatory environment. Moreover, to our knowledge, *no* comprehensive study has ever been undertaken, which models the CAAA *per se* as a particular type of environmental constraint in order to examine their impact on the profit maximizing behaviour of the

[10] Since most of the electric utilities are operating under *ROR* regulation, a brief description of how they work in practice deserves mention. *ROR* regulation, in general, puts a constraint on the maximum rate of return that a utility could earn on its investment. By establishing a *fair return* on investment, the regulator in most cases effectively puts a cap on the price of electricity charged by utilities to their clients, where the term *fair return* refers to the maximum permissible return on utility investment. In most cases, *ROR* regulation are enforced only during intermittent regulatory reviews, rather than continuously, and the fuel adjustment clauses accompanied by them sometimes permit utilities to adjust output prices vis-à-vis fuel cost increases between *rate hearings*. Economists argue that *ROR* regulation often induces overuse of inputs beyond the cost minimizing amounts (Atkinson & Halvorsen, 1986), and thus, utilities tend to adopt non-cost minimizing input ratios (Averch and Johnson, 1962 and Davis, 1973).

electric utility industry in the United States. Thus it is believed that the present study will contribute to filling this important gap in the literature.

Electric utilities are often subject to a number of regulations simultaneously, but the primary emphasis of this study is on environmental regulation, particularly those regulations which accompanied the CAAA. The Amendments to the U. S. Clean Air Act date back to 1970, but the latest set of the Amendments (which came into effect in 1990) can be considered as a benchmark in the U.S. history of environmental regulation, since it initiated the use of market-based instruments to protect the environment. Some scholars have already attempted to explore several dimensions of the Amendments of both 1970 and 1990, and have made several useful observations relevant to the subject matter of this paper. In what follows, therefore, we provide a brief summary of the most relevant of those studies along with their observations and key findings.

Barbera and McConnel (1990) consider an industry subject to an environmental constraint, and attempt to measure any productivity effects by estimating a cost function. In their model, the regulated firms are endowed with a two-output technology, while emissions are assumed to be a by-product, with the only option for compliance being to invest in abatement capital. Applying their model to five manufacturing industries, they find that the productivity growth in the U. S. manufacturing sector has declined by between 10% to 30% during the 1970s, due to the environmental regulations accompanying the Amendments of 1970. However, the specification of their cost function cannot be used in the case of the electric power industry, since utilities now have the freedom to choose from a number of compliance options such as investing in abatement capital, adjusting output, use of new technologies, buying emission permits, etc..

Gollop and Roberts (1983) examine the impact of the Amendments of 1970 on the productivity growth of constrained utilities. Centering their discussion on a firm-specific regulatory intensity variable, they attempt to shed light on the productivity effects and the regulation-induced *fuel-switching* by electric utilities. They find that the more intensive regulations the firms face, the more cost they incur due to expensive low-sulfur fuel, or due to installing scrubbers. Using a data sample of 56 electric utilities over the 1973-79 period, they show that the Amendments of 1970, on average, have lowered the productivity growth of regulated utilities by about 0.59% per annum. However, their assumption that each firm minimizes its production costs is not plausible, because firms confronted with a regulatory constraint fail to minimize their actual costs of production, and thus the marginal rates of technical substitution are *no longer equal* to the ratios of market prices (Atkinson and Halvorsen, 1998). Thus, if one were to measure the impact of environmental regulation, such as that of the CAAA, on the productivity of electric utilities, then the estimation of a total cost function with actual market prices of inputs is not appropriate. [11]

Atkinson and Halvorsen (1984) perform parametric efficiency tests using a generalized cost function with shadow input prices to determine whether utilities subject to regulation actually minimize their production costs, given market prices of inputs. In particular, they try to measure the effect of the allocative inefficiency of inputs due to regulation on total costs and input demand. Analyzing a data set (a cross section for the year 1970) for 123 privately-owned utilities, they find that the presence of regulatory constraints indeed makes the marginal rates of technical substitution between inputs differ from the ratio of market prices, and that regulations typically cause distortions in the ratios of capital-labour and fuel-labour, but not capital-fuel. Since they do not consider any environmental constraints, their model has to be modified if it were to be used in examining the effects of allocative inefficiency of inputs caused by the CAAA.

Matsukawa *et al.* (1993) examine the impact of both environmental regulation and technical change on fuel choice, as well as the effects of price on fuel substitution. They

[11] This observation reiterates the classic finding of Averch and Johnson (1962). To overcome this difficulty, shadow input prices will be incorporated into the specification of the cost function.

use a pooled data set relating to the Japanese manufacturing sector. The empirical results of their study, based on the estimation of a translog cost function, suggest that environmental regulation and technical change significantly affect fuel consumption of most manufacturing industries in Japan. Even though this study makes several useful observations as to how market-based environmental regulation may lead to technical change, and affect fuel consumption, its emphasis on the Japanese manufacturing sector has to be changed substantially if one were to make it applicable to the case of U.S. electric utilities. On the one hand, the intensity and the nature of the U.S. environmental regulation, particularly the CAAA governing the electric utility industry, are significantly different from those in Japan (Fuss and Waverman, 1990). On the other hand, the production characteristics of power generation by coal-fueled U.S electric utilities are unique in many respects since they reflect the local market conditions and prices (Goto, 1998). For these reasons, such a study can only be used in a cross-country comparison analysis.

Lasserre and Ouellette (1994) consider an industry in which firms produce a single output using a vector of variable inputs and capital as a *quasi-fixed* input. [12] They construct a model where firms maximize profits subject to two constraints: a technological constraint represented by a production function, and a regulatory constraint which dictates that revenue less operating costs per unit of capital must not exceed a *fair rate* of return. To analyze the effects of the *ROR* regulation they consider the cost minimization problem (dual to profit maximization) using a *two-step* procedure suggested by Diewert (1981). [13] Their study is purely theoretical. Besides the elaboration of the two-step procedure in the context of a cost function, the derivations of this paper, too, are subject to the same

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[12] For a review of the existing arguments among economists on how to classify inputs as *quasi-fixed* or *variable*, see Appendix III.

[13] The first step of the Diewert's (1981) two-step procedure is to minimize restricted costs (excluding capital expenditure) with respect to variable inputs (x) subject to the technological constraint *only*, and then to minimize total costs (the sum of restricted costs and capital expenditure) with respect to capital (k), subject to the regulatory constraint. The advantage of this two-step procedure is that it allows one to derive the *implicit price of capital* because the restricted-cost function being used is a standard function.

criticism made by Atkinson and Halvorsen (1998), namely that the presence of regulation prevents firms from minimizing their actual production costs. Thus, a cost function of the type considered by Lasserre and Ouellette (1994) is also not appropriate for examining the effects of the CAAA.

The foregoing discussion highlights the fact that a number of inadequacies exist in the literature. These should be done away with in order to reap full benefits of the economic analysis of environmental regulation. In particular, the failure to account for actual market conditions where utilities are operating under different kinds of regulatory constraints, stands out as the major weakness in most of the studies. Ignoring this fact and simply relying on a perfectly competitive market structure often leads to misleading conclusions. On the other hand, these previous studies lack an in-depth inquiry into the effects of the CAAA on utility productivity (and cost economies). [14] The need for a fresh analysis is also evident from the divided stand of observers/researchers on the overall effectiveness of the newly introduced market-based environmental regulation.

In part, the lack of consensus among observers is due to the dearth of empirical evidence regarding the impact of the new regulation. To this end, this study uses a new panel data set covering a ten-year period which overlaps the inception of the 1990 Amendments. It is hoped that this would enable one to examine the impact of the CAAA on the electric utility industry in the United States. Hence, the present paper contributes to the existing literature by undertaking a comprehensive econometric analysis of the costs associated with power generation before and after the introduction of the CAAA.

[14] One exception is Yaisawarng and Klien (1994) who considered the effects of SO_2 regulation on productivity in the U. S. electric power industry. They found that the productivity has been on the decline since 1985. However, their investigation is solely based on Data Envelopment Analysis (DEA), the technique that we consider in another paper of this dissertation.

3.3 Cost Function with Shadow Input Prices

The cost function is of much significance for this study, since our inquiry into the cost effects of the CAAA on electric utilities heavily relies on the econometric estimation of a cost function and a set of cost share equations. As noted above, much of the criticism of the previous literature has centered on the absence of *shadow* prices in the theoretical framework. Thus, we begin by assessing the role of shadow input prices in cost functions.

3.3.1 Shadow Prices

Because the presence of regulation prevents utilities from minimizing their actual production expenditure, the estimation of a neoclassical cost function with actual market prices of inputs is not appropriate to analyze the impact of environmental regulation such as the CAAA. A useful way to alleviate this problem is to incorporate *shadow prices* into the cost function, and to replicate the actual behaviour of utilities. However, a problem arises as to how one should estimate shadow prices in such a way that the cost function may take into account the actual behaviour of utilities under the regulatory constraint. In what follows, attempts will be made to address this question.

Let P_i^* denote the shadow price of input *i*:

$$P_i^* = k_i P_i \qquad 3.1$$

where P_i is the market price of input *i*, and k_i is the *factor of proportionality* (also known as the distortion factor) which is input and firm-specific. [15]

Because the differences between shadow and market prices of inputs are dual to differences between *unregulated* and *regulated* quantities of inputs, it is essential that the

[15] The distortion factor (k_i) may also be interpreted as a first-order Taylor series expansion of an arbitrary shadow price function, $g_i(P_i)$, which has the properties $g_i(0) = 0$ and $\partial g_i(P_i)/\partial P_i \geq 0$.

factor of proportionality (k_i) be specified as a function of variables that may cause such a divergence between equilibrium quantities. In general, a number of variables are believed to be driving this wedge between *shadow* and *market* prices of inputs. To begin with consider internal costs of adjustment. This is an important factor that affects equilibrium quantities of *quasi-fixed* inputs [16] such as investment in capital equipment. The channel through which internal costs of adjustment affect the optimal behaviour of utilities is the discount rate (r) (Atkinson and Halvorsen, 1998). Thus, we consider r to be one determinant of shadow prices. As a proxy for the 'economic rate of discount' (r), Moody's Industrial Bond Yield will be used.

Switching inputs (i.e., between low-sulfur and high-sulfur coal) has been a popular strategy for compliance among electric utilities affected by the CAAA (Arimura, 1998). This behaviour tends to change the *input-mix* chosen by those utilities, thus, creating a gap between pre-regulation and post-regulation input prices. Sometimes this gap could be exacerbated by the strategic behaviour of the coal producing firms (Doucet *et al.*, 1997). Thus, it seems useful to consider the rates of change in input usage (Δz_i) as another determinant of shadow prices. Yet some scholars argue that it is essential to have a time index as another determinant of shadow prices in order to reflect the fact that the 'input mix' used by utilities varies over time due to various external factors (Carlson *et al.*, 1998).

It is evident from the foregoing discussion that the choice of an appropriate specification for shadow prices is somewhat arbitrary, and that the researcher must examine which *circumstance-specific* parameters should be included in the specification of shadow prices. At the same time, the researcher has to ensure that the parameters chosen are all justifiable on grounds that each one plays a particular role in the analysis. After carefully considering all such factors, the following specification was chosen for the 'factor

[16] Since the categorization of inputs as *variable* or *quasi-fixed* is an empirical question, *a priori* restrictions will not be placed on any variable in this study. For a detailed discussion of this issue, see Appendix III.

of proportionality' (k_i) in our model:

$$k_{it} = \exp(\delta_{ir} r_t + \delta_{iz} \Delta z_{it} + \delta_{iT} T) \qquad \text{where } i = \text{coal, capital}^{17} \qquad 3.2$$

where r is rate of discount, Δz are annual changes in input usage, and T is an index of time.

3.3.2 Choice of Cost Function

To begin with, it is assumed that there exists a cost function that characterizes the electric utility industry in the United States:

$$C = C(P_i, Q, T) \qquad 3.3$$

where P_i is a vector of input prices, Q is output, and T [18] is an index of time.

There are at least *three* types of flexible functional forms in the literature which are frequently being used to specify cost functions namely, Translog, Generalized Leontief, and Symmetric Generalized McFadden Function. [19] While each type of function has its own merits, most of the recent scholars investigating the firm's cost minimization problem under regulatory constraints have favoured the *translog function.* [20]

The widespread use of the *translog* function can be attributed to several factors. Its easier adaptability to empirical analyses by adding case specific-variables without altering the theoretical properties stands out as one of its major advantages. The translog function places far fewer restrictions on parameters than does any other more traditional Cobb-

[17] In the case of electric utilities, the cost share of labour is typically very low relative to that of coal and of capital inputs. Singh (1991) argues that "....since labour is non-substitutable for fuel and capital, the electric-output is generally treated to be dependent on fuel and capital". In our sample, the average labour cost as a percentage of total production expenditure is between 3% and 4%. Thus, without loss of generality we omit the relatively insignificant labour costs from the analysis.

[18] T can alternatively be interpreted as the rate of technical change which reflects the shifts of the cost function over time (Suer, 1995). In what follows, we discuss this issue in detail.

[19] No attempt is made to discuss the properties of all these functions in this paper. Interested readers can consult Diewert (1971), Diewert & Wales (1987), and Terral (1996) for in-depth discussions.

[20] *Translog* or *Transcendental Logarithmic* functional form was first proposed by Christensen *et al.* (1973). It is a second-order Taylor series approximation in logarithms to any arbitrary function.

Douglas, Leontief, or *CES* function. For example, implicit in these other functional forms are constant elasticities of substitution between inputs and homotheticity of technology. In contrast, generalized cost functions, such as the Translog function, enable testing for specific characteristics of technology, and do not require any *a priori* restrictions on parameters. Furthermore, those other traditional functions steer measures like elasticity of size and elasticities of substitution to depend on the data, and thus such measures could vary across samples. In contrast, with the translog function, it is possible to construct and test various hypotheses that are invariant to the properties of samples.

Since the translog function provides a convenient framework for analyzing the behaviour of electric utilities, the following specific form [21] was chosen for this study:

$$\begin{aligned}\ln C = {} & \alpha_0 + \alpha_Q \ln Q + \sum_i \alpha_i \ln\left(k_i P_i\right) + \sum_n \gamma_n D_n + \alpha_T T + \tfrac{1}{2}\beta_{QQ}\left(\ln Q\right)^2 \\ & + \tfrac{1}{2}\beta_{TT}T^2 + \tfrac{1}{2}\sum_i \sum_j \beta_{ij} \ln\left(k_i P_i\right)\ln\left(k_j P_j\right) + \sum_i \beta_{iQ} \ln Q \ln\left(k_i P_i\right) \\ & + \sum_i \beta_{iT} \ln\left(k_i P_i\right)T + \beta_{QT}\left(\ln Q\right)T \end{aligned} \qquad 3.4$$

where Q is output, [22] P_i is price vector for inputs, D_n is a set of dummy variables [23], T is an index of time which represents the technology-induced shifts of the cost function over time, and k_i and k_j are factors of proportionality.

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[21] The translog cost function of the type specified in (3.4) is a *non-homothetic* function (Berndt, 1991, chap. 9). In Section 3.5, appropriate hypotheses will be established to test whether this function would meet the relevant criteria. The technical conditions concerning the translog function and the problems encountered in its empirical applications are discussed in detail in Appendix III.

[22] The output is measured in terms of millions of kilowatt hours.

[23] In empirical analyses, when using panel data like ours, it is essential to have *firm* and *input* specific dummy variables to capture different structures of each cross-sectional unit in the sample. For details, see the discussion on Qualitative Variables in Section 3.5.5.

3.4 Econometric Model [24]

3.4.1 Theoretical Considerations

Consider a power generating plant faced with the problem of minimizing its total cost of production. Assume that the plant takes into account the shadow prices of inputs.

Let the total shadow cost (C^*) be:

$$C^* = \sum_i P_i^* X_i = C^*\left(P_i^*, Q, T\right) \qquad 3.5$$

where P_i^* is the vector of shadow input prices. By applying Shephard's lemma to (3.5), we derive the input demand functions:

$$X_i = \frac{\partial C}{\partial P_i^*} = f\left(P_i^*, Q, T\right) \qquad 3.6$$

By differentiating (logrithmically) the shadow cost function in (3.4) we obtain:

$$\frac{\partial \ln C^*}{\partial \ln (k_i P_i)} = \left[\frac{k_i P_i}{C^*}\right]\left[\frac{\partial C^*}{\partial (k_i P_i)}\right] = \alpha_i + \sum_j \beta_{ij} \ln\left(k_j P_j\right) + \beta_{iQ} \ln Q + \beta_{iT} T \qquad 3.7$$

Using Shepard's lemma, the expression in (3.7) can alternatively be written as:

$$\frac{\partial \ln C^*}{\partial \ln (k_i P_i)} = \left[\frac{k_i P_i}{C^*}\right]\left[\frac{\partial C^*}{\partial (k_i P_i)}\right] = \frac{k_i P_i X_i}{C^*} \qquad 3.8$$

where X_i are the input demand functions.

In econometric literature, the expression in (3.7) is often referred to as the *shadow cost share of input i*. For notational convenience, let us denote it by M_i^* and rewrite it as:

$$M_i^* = \alpha_i + \sum_j \beta_{ij} \ln\left(k_j P_j\right) + \beta_{iQ} \ln Q + \beta_{iT} T \qquad 3.9$$

[24] This section draws from Atkinson & Halvorsen (1994 and 1998), and Kumbhakar (1996).

where * denotes the *shadow* cost share.

Now combining (3.8) and (3.9), the input demand function for input i can be written as:

$$X_i = M_i^* C^* (k_i P_i)^{-1} \qquad 3.10$$

Since data on either C^* or M_i^* do not exist, expressions for the *actual total cost* (C) and the *actual cost shares* (M_i) must be derived.

By definition the actual total cost is equal to:

$$C = \sum_i P_i X_i \qquad 3.11$$

Substituting (3.10) into (3.11) and taking logarithms, we could obtain:

$$\ln C = \ln C^* + \ln \sum_i k_i^{-1} M^* \qquad 3.12$$

The *estimable form* for the cost function is derived by substituting (3.4) and (3.9) into (3.12):

$$\begin{aligned}\ln C = {} & \alpha_0 + \alpha_Q \ln Q + \sum_i \alpha_i \ln (k_i P_i) + \sum_n \gamma_n D_n + \alpha_T T \\ & + \tfrac{1}{2}\beta_{QQ}(\ln Q)^2 + \tfrac{1}{2}\beta_{TT}T^2 + \tfrac{1}{2}\sum_i \sum_j \beta_{ij} \ln (k_i P_i) \ln (k_j P_j) \\ & + \sum_i \beta_{iQ} \ln Q \ln (k_i P_i) + \sum_i \beta_{iT} \ln (k_i P_i) T \\ & + \beta_{QT}(\ln Q)T + \ln \left[\sum_i k_i^{-1} \left(\alpha_i + \sum_j \beta_{ij} \ln (k_j P_j) + \beta_{iQ} \ln Q + \beta_{iT} T \right) \right]\end{aligned} \qquad 3.13$$

Similarly, an estimable form can also be obtained for the actual cost shares:

$$M_i = \frac{P_i X_i}{C} \qquad 3.14$$

Substituting for X_i and C using equations (3.10) and (3.12), respectively, we obtain:

$$M_i = \frac{M_i^* k_i^{-1}}{\sum_i M_i^* k_i^{-1}} \qquad 3.15$$

Replacing M_i^* using (3.9) we obtain:

$$M_i = \frac{\left[\alpha_i + \sum_j \beta_{ij} \ln\left(k_j P_j\right) + \beta_{iQ} \ln Q + \beta_{iT} T\right] k_i^{-1}}{\sum_i \left[\left(\alpha_i + \sum_j \beta_{ij} \ln\left(k_j P_j\right) + \beta_{iQ} \ln Q + \beta_{iT} T\right) k_i^{-1}\right]} \qquad 3.16$$

3.4.2 Conceptual Issues

In order for the model to be consistent with economic theory, it is necessary to place certain restrictions on the parameters in both (3.13) and (3.16). The first restriction has *two* components to it, which together ensure that the cost function is homogeneous of degree *one* in input prices.

$$\sum_i \alpha_i = 1 \quad \Rightarrow \quad \alpha_1 + \alpha_2 = 1 \qquad 3.17$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{iQ} = 0 \qquad 3.18$$

By expanding conditions (3.17) and (3.18) we obtain:

$$\begin{aligned} \beta_{11} + \beta_{21} &= 0 \\ \beta_{12} + \beta_{22} &= 0 \\ \beta_{11} + \beta_{12} &= 0 \\ \beta_{21} + \beta_{22} &= 0 \\ \beta_{1Q} + \beta_{2Q} &= 0 \end{aligned} \qquad 3.19$$

The symmetry of the Slutsky matrix of cross-derivatives of the cost function implies that $\beta_{ij} = \beta_{ji}$ for $i \neq j$. Thus:

$$\beta_{12} = \beta_{21} \qquad 3.20$$

Now (3.19) and (3.20) together imply that restrictions in (3.18) can be satisfied by setting:

$$\beta_{11} = \beta_{22} \quad \text{and} \quad \beta_{1Q} = -\beta_{2Q} \qquad 3.21$$

In addition to the above parameter restrictions, several other conditions must also be verified because the translog function need not always be well behaved for all input price combinations. For example, to reflect the fact that an increase in an input price must lead to an increase in total costs, the cost share equations derived from (3.4) must be non-negative at each and every data point in our sample. Checking for the non-negativity of cost share equations is often referred to as checking for *monotonicity* or *positivity*.

It is possible to check for monotonicity of the cost function by testing whether the estimated shadow cost shares (M_i^*) are all positive, i.e., $\frac{\partial C}{\partial Q} > 0$, which implies that:

$$\alpha_Q + \beta_{QQ} \ln Q + \sum_i \beta_{iQ} \ln\left(k_i P_i\right) + \beta_{QT} T > 0 \qquad 3.22$$

In addition, the cost function should also satisfy a set of *concavity* conditions. [25] This requires that the Hessian matrix [26] should be negative semi-definite.

$$\boldsymbol{H} = \begin{bmatrix} \left(\beta_{11} + \left(M_1^*\right)^2 - M_1^*\right) & \left(\beta_{12} + M_1^* M_2^*\right) \\ \left(\beta_{21} + M_2^* M_1^*\right) & \left(\beta_{22} + \left(M_2^*\right)^2 - M_2^*\right) \end{bmatrix} \qquad 3.23$$

There are a few other minor technical requirements as well. First, we must append a classical disturbance term to each of the equations to account for random errors in optimization (Berndt, 1991, Chapter 9). Such disturbance terms are presumed to be

[25] In the case of the translog cost function, the concavity condition is a local property and can be imposed only locally (Wiley, *et al.*, 1973).
[26] The Hessian matrix, in this context, is the matrix of derived-demand elasticities (Chambers, 1988).

intertemporally independent, multivariate normal with zero mean and non-zero contemporaneous covariances. Furthermore, *one* of the cost-share equations should be dropped from the system of share equations in order to avoid the contemporaneous covariance matrix for the disturbances being singular. [27] This is because the adding-up constraints imply cross-equation dependency in error terms. One other requirement for translog cost functions with shadow input prices is that they must be homogeneous of degree zero in k_i [28] and thus *one* of the k_i must also be normalized by setting it equal to unity (Atkinson and Halvorsen, 1998). Accordingly, it is set that $k_2 = k_{cap} = 1$ making it a *numeraire*.

In addition, we examined carefully the other typical econometric problems which arise in estimating production and cost functions using panel data. Questions of sample selectivity, serial correlation due to unobserved firm effects, and endogeniety were addressed. In places where such problems appear to exist, we discuss the remedial measure(s) adopted in this study.

3.4.3 Model Specification

The model consists of a cost function and a set of cost-share equations. After taking into account the parameter restrictions (3.17) through (3.21) and the other technical conditions, the *final estimable form* of the translog cost function can be written as:

[27] Dropping *one* of the cost share equations is necessary to prevent the system of cost-share equations from summing up to unity at every sample point. Even though the choice of the cost-share equation to be dropped is arbitrary, estimation results would be independent of the equation being dropped if the standard assumptions on the error structure are maintained, and if the iteration procedure is used in estimation (Bernd and Savin, 1975). For example, if the Iterative Zellner method (we employ this method) is used, the estimation results would be invariant to the choice of equation being dropped (Berndt, 1991). Thus, as an experiment, we attempted the estimation procedure first by dropping the *coal-share* equation, followed by the *capital-share* equation, and the result was that the estimated coefficients are invariant to the *cost-share* equation being dropped.

[28] This is also true for all of the cost share equations derived from the translog functions (Halvorsen, 1977).

$$\ln C=\alpha_0+\alpha_Q\ln Q+\alpha_1\ln(k_1P_1)+(1-\alpha_1)\ln(k_2P_2)+\gamma_1D_1+\alpha_TT+\tfrac{1}{2}\beta_{QQ}(\ln Q)^2+\tfrac{1}{2}\beta_{TT}T^2$$
$$+\tfrac{1}{2}\beta_{11}\left[(\ln(k_1P_1))^2+(\ln(k_2P_2))^2\right]+\beta_{12}\ln(k_1P_1)\ln(k_2P_2)+\beta_{1Q}\ln Q\left[\ln(k_1P_1)-\ln(k_2P_2)\right]$$
$$+\beta_{1T}\ln(k_1P_1)T+\beta_{2T}\ln(k_2P_2)T+\beta_{QT}(\ln Q)T \qquad \textbf{3.24}$$
$$+\ln\left[k_1^{-1}\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(k_2P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)+k_2^{-1}\left((1-\alpha_1)+\beta_{12}\ln(k_1P_1)+\beta_{11}\ln(k_2P_2)-\beta_{1Q}\ln Q+\beta_{2T}T\right)\right]$$

where subscripts 1 and 2 denote *coal* and *capital* inputs respectively.

Similarly, the cost share equation for coal can be derived from (3.16) by incorporating all of the parameter restrictions:

$$M_1=\frac{\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)}{\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)+\left(1-\alpha_1+\beta_{12}\ln(k_1P_1)+\beta_{11}\ln(P_2)-\beta_{1Q}\ln Q+\beta_{2T}T\right)k_1} \qquad \textbf{3.25}$$

3.5 Testable Hypotheses

The econometric model developed above provides the basis for testing a number of hypotheses. It is essential to investigate not only the *nature* and the *magnitude* of the effects of the CAAA, but also the *significance* and the *robustness* of the coefficient estimates of our model. A number of hypotheses are established to examine various dimensions of the behaviour of electric utilities under the CAAA.

3.5.1 Properties of the Equilibrium

Even though the testing of the model's equilibrium properties is not a prime objective of this study, the construction of several other hypotheses (to be described below) requires that we examine whether the model has met the standard properties of equilibrium. Thus, we begin with the tests of static equilibrium properties that are based on the comparison of *shadow* and *actual* market prices of inputs.

In this model, full-static equilibrium is attained if the total actual cost of producing the output is minimized in each period, i.e., if all marginal rates of technical substitution (*MRTS*) are equated to the corresponding ratios of actual input prices. Partial static equilibrium is attained if *MRTS* are equated to the ratios of actual input prices for some, but not all, pairs of inputs. In terms of economic theory, the assumption that utilities minimize total shadow cost implies that *MRTS* will be equal to the corresponding ratios of shadow prices. Thus, the static equilibrium requires the equality of shadow and actual input price ratios.

From (3.1) and (3.2), we can derive a shadow price ratio for coal (i) and capital (j) in terms of actual market prices:

$$\frac{P_{it}^*}{P_{jt}^*} = \left[\frac{k_{it}}{k_{jt}}\right]\left[\frac{P_{it}}{P_{jt}}\right] \qquad 3.26$$

Expression (3.26) implies that full static equilibrium will be attained if $k_{it} = k_{jt}$ for *both* coal and capital, whereas partial equilibrium will be attained if $k_{it} = k_{jt}$ for *either* coal or capital, but *not* both. As it is necessary that the total actual cost equation and the actual cost share equations are homogeneous of degree zero in the k_i, the k_i are identifiable only up to a constant of proportionality, and the estimation requires that one of them be normalized. Estimates of the relative values of the k_i, as well as all other parameters, are invariant to the choice of which k_i to normalize and its assigned value (Atkinson and Halvorsen, 1998). Since we have set $k_{2t} = k_{cap} = 1$ making it a *numeraire*, using (3.2), $k_{coal} = k_{1t}$ can be written as:

$$k_{1t} = \exp\left(\delta_{1r} r_t + \delta_{1z} \Delta z_{1t} + \delta_{1T} T\right) \qquad 3.27$$

Full static equilibrium is attained if $k_{1t} = k_{2t}$. Given $k_{2t} = k_{cap} = 1$ (i.e., normalization), the condition for full equilibrium is $k_{1t} = k_{coal} = 1$, and the corresponding parameter restriction is:

$$\delta_{1r} = \delta_{1z} = \delta_{1T} = 0 \qquad 3.28$$

where subscript I denotes coal input.

If the condition for full-static equilibrium given in (3.28) [29] is rejected, further light could be shed on the source of rejection by constructing an alternative hypothesis which is often referred to as the *dynamic equilibrium.* This is one of the cases where testing of the equilibrium properties of the model is essential to proceed further. As argued before, one of the roles played by both the discount rate (*r*) and the changes in the quantities of inputs (Δz_i) included in the specification of shadow prices (3.27) is that together they account for any divergences between actual and static equilibrium quantities of inputs in the presence of internal costs of adjustment. [30] Thus, the empirical relevance of the dynamic equilibrium specification can be examined by testing the joint significance of the discount rate and changes in the quantities of inputs:

$$\delta_{1r} = \delta_{1z} = \delta_{2r} = \delta_{2z} = 0 \qquad 3.29$$

Furthermore, in this framework, the likely effects of the CAAA can be interpreted as a *departure* from static equilibrium and can be examined by testing whether the other terms included in shadow price proportionality factors are consistent with static equilibrium. The corresponding parameter restriction is:

$$\delta_{1T} = \delta_{2T} = 0 \qquad 3.30$$

[29] Notice that since two inputs exists, the full static equilibrium coincides with the partial static equilibrium in this particular case.

[30] See, in particular, Atkinson (1980), Chambers (1988), and Atkinson and Halvorsen(1986).

Testing for ***homotheticity*** and ***homogeneity*** is required in order to verify if the model is consistent with economic theory. Since our estimation does not constrain the structure of production to be homogeneous or homothetic, we test these restrictions statistically. A cost function is homothetic, if and only if it can be written as a separate function in output and input prices, i.e., $C(Q, P_i) = h(Q)C(P_i)$. Homotheticity [31] of the production function is tested by imposing the following parameter restrictions on the cost function (3.24).

$$\beta_{1Q} = \beta_{2Q} = 0 \qquad 3.31$$

Conditional on the acceptance of homotheticity, a production structure is homogeneous if and only if the elasticity of cost with respect to output is constant. Homogeneity is tested by imposing the additional restriction:

$$\beta_{QQ} = 0 \qquad 3.32$$

3.5.2 Technological Change

The investigation into the technological change induced by the CAAA involves several steps. First, we identify the *nature* of the technological change, if any, its *bias* towards input use, and finally, its *magnitude*.

We begin by using the estimated coefficients of the model in order to determine the *nature* of the technological change by testing for its types. Two generic types of technological change, namely *Hicks' neutral* and *Harrod's neutral* are considered.

Hicks' neutral technological change requires that:

[31] Another way to view homotheticity is to recognize the fact that it requires that all inputs be normal and that input ratios be independent of the level of output. Based on this observation, a crude test for local homotheticity can be constructed on the elasticity of input demand with respect to scale: $h_Q = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \beta_{QQ} \ln Q + \beta_{1Q}\left[\ln(k_1 P_1) - \ln(k_1 P_1)\right] + \beta_{QT} T$. Homotheticity requires that $h_Q > 0$.

$$\beta_{1T} = \beta_{2T} = 0 \qquad 3.33$$

Harrod's neutral technological change requires that:

$$\beta_{1T} + \beta_{2T} = 0 \qquad 3.34$$

It may also be possible that *no* technical change has occurred due to the CAAA. We test the hypothesis of *no* technical change by imposing the following restriction: [32]

$$\alpha_T = \beta_{TT} = 0 \qquad 3.35$$

The second way to determine the rate of technological change (τ) induced by the CAAA is to use the resulting parameter estimate of the index of time (T). Using the translog cost function in (3.24) we can define τ [33] as:

$$\tau = -\frac{\partial \ln C}{\partial t} = -\left[\alpha_T + \beta_{TT}T + \beta_{1T}\ln(k_1P_1) + \beta_{2T}\ln(k_2P_2) + \beta_{QT}\ln Q + \left(\frac{\beta_{1T} + k_1\beta_{2T}}{\Delta k_1}\right)\right] \qquad 3.36$$

where

$$\Delta = k_1^{-1}\left(\alpha_1 + \beta_{11}\ln(k_1P_1) + \beta_{12}\ln(k_2P_2) + \beta_{1Q}\ln Q + \beta_{1T}T\right) + k_2^{-1}\left(1 - \alpha_1 + \beta_{12}\ln(k_1P_1) + \beta_{11}\ln(k_2P_2) - \beta_{1Q}\ln Q + \beta_{2T}T\right)$$

In this formulation α_T measures the rate of *neutral* technological change (*TC*), whereas β_{1T} and β_{2T} account for the rates of price-induced *TC*. Furthermore, $\beta_{1T}, \beta_{2T} > 0$ implies that *TC* is *input-using* while $\beta_{1T}, \beta_{2T} < 0$ suggest that it is *input-saving*.

Finally, we divided (3.36) into *three* components in order to consider the nature of the

[32] The sample in hand also provides information on *land and land rights*, *structures and improvements*, and *equipment costs*, which add up to the total value of capital assets at the end of each year. Since the difference between *any* two consecutive years is the net investment which the utilities have undertaken, the possibility of constructing another hypothesis was considered in order to test the likely effects of the CAAA on utility investment. However, as utilities simultaneously invest in both *productive* and *abatement* capital, it was necessary to identify each component separately. However, the limitations of the data set did not permit such a scenario.

[33] In this context, τ can alternatively be interpreted as the rate of cost reduction resulting from technological change (Pescatrice and Tarapani III, 1980).

technological change, namely *pure* (*PTC*), *factor-biased* (*FTC*), and *scale-augmenting* (*STC*) technological change: [34]

$$PTC = \alpha_T + \beta_{TT}T \tag{3.36a}$$

$$FTC = \beta_{1T}\ln(k_1P_1) + \beta_{2T}\ln(k_2P_2) \tag{3.36b}$$

$$STC = \beta_{QT}\ln Q \tag{3.36c}$$

3.5.3 Economies of Scale

Economies of scale can be defined as the relative increase in output resulting from a proportional increase in all inputs. Hanoch (1975) demonstrates that often it is more relevant to measure scale economies by using the relationship between total cost and output along the expansion path. In the present context, *two* concepts of returns to scale are relevant. The relationship between total actual cost and output corresponds to the usual definition of returns to scale, and is relevant for evaluating the optimum scale of utilities from a public policy (i.e., environmental regulation) point of view. On the other hand, the relationship between total shadow cost and output is a relevant concept for evaluating the optimal scale of utilities from their own point of view, because it is shadow cost, rather than total actual cost, that the utilities will presumably minimize.

Next, we set up a hypothesis to test whether the production technology used by utilities exhibit constant return to scale. The parameter restrictions used to test this hypothesis are:

$$\alpha_Q = 1,\ \beta_{1Q} = \beta_{2Q} = \beta_{QQ} = \beta_{QT} = 0 \tag{3.37}$$

The elasticity of total *actual cost* (ε_{CQ}) with respect to output is derived from (3.4):

[34] Recently, a similar procedure was adopted by Okunade and Suraratdecha (1998) in order to examine the nature of the technological change in the pharmaceutical sector in the United States.

$$\varepsilon_{CQ} = \frac{\partial \ln C^*}{\partial \ln Q} = \alpha_Q + \beta_{QQ} \ln Q + \sum_i \beta_{iQ} \ln \left(k_i P_i\right) + \beta_{QT} T + \left(\frac{\left(1 - k_1\right)\beta_{1Q}}{\Delta k_1}\right) \qquad 3.38$$

where

$$\Delta = k_1^{-1}\left(\alpha_1 + \beta_{11} \ln \left(k_1 P_1\right) + \beta_{12} \ln \left(k_2 P_2\right) + \beta_{1Q} \ln Q + \beta_{1T} T\right) + k_2^{-1}\left(1 - \alpha_1 + \beta_{12} \ln \left(k_1 P_1\right) + \beta_{11} \ln \left(k_2 P_2\right) - \beta_{1Q} \ln Q + \beta_{2T} T\right)$$

The formula for the elasticity of total *shadow cost* with respect to output differs from (3.37) in such a way that it does not include the last term of equation (3.37). Since this term may be either positive or negative, the elasticity of total shadow cost may be either smaller or larger than the elasticity of total actual cost. The elasticity measures described above can be translated into *scale economies* (*SE*) by defining them as: [35]

$$SE = 1.0 - \frac{\partial \ln C}{\partial \ln Q} \quad \text{and} \quad SE^* = 1.0 - \frac{\partial \ln C^*}{\partial \ln Q} \qquad 3.38a$$

Scale economies are independent of factor prices if and only if the production function is homothetic. The production function is restricted to be homothetic if and only if the shadow cost function can be written as a separable function in prices and output. In addition, the production function is further restricted to be homogenous if and only if the elasticity of cost with respect to output is constant. [36] [37]

3.5.4 Elasticities of Substitution and Prices

The estimates of elasticities of substitution and prices are extremely valuable both as a description of technology and as a means of comparison. They are alternate, conceptually

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[35] Multiplication by 100 yields estimates of scale economies expressed as percentages.
[36] As part of the discussion of the 'Technical Considerations' above, the parameter restrictions necessary to test both the *homotheticity* and *homogeneity* of the production function will be specified.
[37] Okunade and Suraratdecha (1998) show that *economies of scale* can also be defined (at the mean point of expansion) using: $ESCALE = 1 - \left(\frac{\partial \ln C}{\partial \ln Q}\right)$. A negative (positive) estimate of *ESCALE* indicates diseconomies (economies) of scale, whereas a zero estimate implies a constant cost. These results are the same as (3.37). For another viewpoint, see Blackorby and Russell (1989).

different ways of measuring substitution possibilities among inputs. The most commonly used are *two* types of elasticities, namely the *Allen* Partial Elasticity of Substitution (*AE*) and the *Morishima* Elasticity of Substitution (*ME*). [38] The difference between the two measures can best be understood in the context of cost-minimizing behaviour.

The AE_{ii} (denoted by E_{ii}) is the *own-price elasticity of demand* for factor *i*. It measures the responsiveness of factor *i* to changes in its own price and can be measured as:

$$E_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2} \qquad 3.39$$

where S_i and S_j are cost shares.

The AE_{ij} (denoted by E_{ij}) is the *cross-price elasticity of demand* for factor *i* with respect to the price of factor *j*, divided by the *j*th cost share. It measures the responsiveness of factor *i* to changes in the price of factor *j* (in terms of logarithmic derivatives) and is symmetric ($E_{ij} = E_{ji}$):

$$E_{ij} = \frac{\beta_{ij} + S_i S_j}{S_i S_j} \qquad i \neq j \qquad 3.40$$

where S_i and S_j are cost shares. [39]

The ME_{ij} (denoted by M_{ij}), on the other hand, measures the responsiveness of the *ratio* of the demand for factor *i* and *j* to a change in the price of the i^{th} factor. Since M_{ji} measures the responsiveness of the ratio of demands to changes in the j^{th} price, it is not symmetric.[40]

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[38] In general, inputs are classified as substitutes if the elasticity of substitution is positive, and as complements if it is negative. As we will see, input classification may not always be independent of the choice of the elasticity measure.

[39] There is an alternative way to verify the concavity of the cost function. Notice that the price elasticity of input demand for production (ε_{ij}) can be directly calculated from the AES as: $\varepsilon_{ij} = E_{ij} S_j$. Once the estimate $\Sigma = [E_{ij}]$ is obtained, the matrix of the price elasticity of input demands (θ) can be calculated as: $\theta = \Sigma S$. Then, the necessary and sufficient condition in order that the translog cost function to be concave is that all the eigen values of matrix Σ be non-positive. In other words, the matrix of Allen elasticity of substitution is negative semi-definite.

[40] For a more detailed discussion of partial elasticities of substitution and the differences between AES and MES, consult Chambers (1988), pp. 27-36, 93-100.

ME_{ij} is defined as a logarithmic derivative of a quantity ratio with respect to a marginal rate of substitution or a ratio of input prices:

$$M_{ij} = \frac{\beta_{ij} + S_i S_j}{S_j} - \frac{\beta_{ii} + S_i^2 - S_i}{S_i} \qquad i \neq j \qquad 3.41$$

where S_i and S_j are cost shares. [41]

The MES_{ij} can also provide complete information about relative factor cost shares in response to a change in factor prices (Huang, 1991). This measure can be written as:

$$\eta_{ij} = 1 - M_{ij} \qquad 3.42$$

The relative cost share is decreasing (increasing) if the MES_{ij} is greater (less) than one.

3.5.5 Qualitative Variables

To examine the relationship between 'utility-specific' characteristics and the likely effects of the CAAA, several *qualitative* variables are considered in the form of dummy variables. [42]

3.5.5.1 Size of Utility

A dummy variable representing *size* is introduced to account for the scale of operation of the affected utilities. Using installed megawatt capacity as a proxy for '*size*', each utility is classified as *large* or *small*, where large utilities are those with an installed capacity which exceed the industry-median, while the rest are considered small utilities. The

[41] The AES measures are the most commonly presented elasticity measures in the literature. They are useful for verifying whether the estimated functions satisfy the regulatory conditions required for well-behaved cost functions because these conditions can be expressed as relatively simple functions of AES. However, in cases where more than two inputs are considered, the MES measure is preferred, since, in such cases, the AES measure fails to account for the curvature properties of the isoquants and the relative cost shares, and hence, the resulting marginal rates of substitution become questionable (Blackorby and Russell, 1989).

[42] As noted before, some of these dummies (for example, *firm-specific* dummies) are essential in order to capture different structures of each cross-sectional unit in our panel data set (Johnston, 1984).

objective is to examine if the likely effects of the CAAA are variant to the 'capacity' of utilities. Some scholars (e.g., Kumbhakar, 1993b) have shown that the scale of operation at which utilities function, can be used to draw inferences about economies of scale and the characteristics of production technology. Thus, we integrate our findings here with those of the scale hypotheses to examine what they could offer with regard to the new regulation.

3.5.5.2 Pre-regulation period *versus* Post-regulation period

This dummy variable is central to our analysis as it accounts for the likely effects of the CAAA across *two* time periods. The ten-year [43] period (1985-94) covered by the sample is divided into two periods, namely the pre-regulation period (1985-89) and the post-regulation period (1990-94). [44] The goal is to determine if there has been any significant change in the behaviour of electric utilities following the passage of the CAAA.

3.5.5.3 Location Characteristics

Sometimes geographical factors could also influence the production activities of the utilities. We use *three* dummy variables in order to distinguish the location of each utility. The dummy variables represent the *three* regions of the United States, namely *Midwest*, *Northeast*, and *Southeast*. The choice of these three regions is to reflect a "even" distribution of utilities (included in the sample) across the country. The resulting coefficient estimates will be used to examine the significance of *location* as another factor influencing the behaviour of utilities.

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[43] The sample covers an *eleven-year* period from 1984 to 1994. However, because the construction of some variables in the model required the data to be lagged one year, a *ten-year* period from 1985 to 1994 was chosen to ensure a 'balanced' panel data set.

[44] As an experiment, the model was also estimated by redefining this dummy variable as one that takes on the value of *0* for years 1985-89 and *1* for years 1990-94. The results are presented in Table 1 in Appendix III.

3.5.5.4 Firm-Specific Dummies

Since a panel data set is used, it is essential that we account for cross-sectional variations in the sample. Ignoring such variations would give rise to biased parameter estimates (Atkinson and Halvorsen, 1998). Thus we introduce into our model 68 *utility-specific* dummy variables to capture the different structures of each cross sectional unit.

3.5.6 Tests for Special Cases

The null hypothesis that factors of proportionality (k_i) do not vary over time, is tested by imposing the following restrictions:

$$\delta_{1T} = \delta_{2T} = 0 \qquad 3.43$$

If this hypothesis is rejected, failure to incorporate the time variable as part of the distortion factors will cause a bias in measuring the total rate of technological change.

To test if the utilities attain *cost efficiency* of inputs, we must test whether $k_i = k_j = 1$ (where i = coal and j = capital), as assumed in Gollop and Roberts (1983). The relevant parameter restrictions are:

$$\delta_{1r} = \delta_{2r} = \delta_{1z} = \delta_{2z} = \delta_{1T} = \delta_{2T} = 0 \qquad 3.44$$

If the hypothesis in (3.44) [45] cannot be rejected, then it can be concluded that utilities minimize their actual costs of production. Otherwise, it will be possible to confirm the argument that the use of a neoclassical cost function gives biased estimates concerning the true characteristics of the production function. [46]

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[45] Notice that this hypothesis has similarities with (3.25), which tests the properties of the static equilibrium.

[46] Equation (3.44) is of particular importance for next chapter (Chapter 4) which is based on Data Envelopment Analysis (DEA), where we explore the efficiency aspects of the CAAA.

3.6 Data Sources and Definitions

3.6.1 Sources of Data [47]

The data set used in this dissertation is compiled from the Federal Energy Regulatory Commission (FERC), the national institution which oversees federal regulation governing the electric utility industry in the United States. FERC has established a number of standard forms to collect data from *coal-fired* electric utilities on both a monthly and an annual basis. Most of our data are from the *FERC Form 1*, [48] the mandatory annual report submitted by coal-fired electric utilities. The sample includes both cost and production data for 68 leading coal-fueled [49] U. S. electric utilities over the ten-year period from 1985 to 1994. [50] Of these power generating plants, 53 are investor-owned, and 15 are publicly-owned utilities. The sample include eight of the twelve most polluting power plants owned by power utility companies in the United States (http://www.epa.gov).

3.6.2 Definitions

The cost of production (*C*) is the total cost of generating electricity. Output (*Q*) is the *net* generation of electricity measured in thousands of kilowatt hours. The raw data on the price of coal (P_c) represent the delivered price per ton of coal at plant sites. To make it

[47] A detailed description of the data set and the other constructed series is provided in Appendix I.
[48] A specimen of the FERC Form No. 1 is attached to Appendix I.
[49] These utilities (or plants) remained as coal-fuelled utilities throughout the sample period, i.e., 1985-1994.
[50] Since the primary goal of this study is to examine the effects of the CAAA, the length of the time series has been chosen to enable meaningful comparisons between pre- and post-regulatory periods. It should be noted, however, that the data set used in this study has been compiled as part of another research assignment, and that the budgetary limitations did not permit us to update it beyond the year 1994. Nevertheless, most recent studies examining the U.S. SO_2 program (Schmalensee, *et al*, 1998 and Stavins, 1998a) find that the utilities affected by the CAAA had started responding to the new environmental measures as early as 1991, despite the fact that Phase I of the CAAA had been scheduled to begin only in 1995 (See in particular, Ellerman *et al.*, 2000). These studies further show that such behaviour is consistent with both inter-temporal optimization and the long-term nature of the investment contracts agreed upon by the utilities. Thus, we believe that our data set is extensive enough to shed light on the behaviour of electric utilities affected by the CAAA.

applicable to this study, we adjusted the price of coal by using the *Btu* content as a weighting factor, where the *Btu* factor is also taken from the FERC's Form 1.

The price of capital (P_k) (i.e., implicit rental price) was calculated using a method developed by Jorgenson (1963) and Coen (1968). They define the *user cost of capital* (P_k) as $P_k = \left[g(\delta + s)(1 - uB)\right]/(1 - u)$, where g is cost per unit of capital, δ is economic rate of depreciation, s is rate of return, u is corporate income tax rate, and B is the present value of the tax depreciation allowed for one dollar's investment: $B = \sum_{l=1}^{\infty} d_l(1+s)^{-l}$. For g, we chose the 'Handy-Whitman Price Index' taken from the Moody's Nation Wide Survey of Public Utility Progress, while $d = 0.045$ was adopted from Christensen *et al.* (1980).[51] For the rate of return (s), Moody's Industrial Bond Yield was selected. Following Coen (1968), the useful life of a utility for tax purposes (l) was taken to be 18 years, and it was assumed that the government permits utilities to write off its plant(s) in 18 years by equal installments.

Moody's Industrial Bond Yield[52] was used as a proxy for the rate of discount (r). Changes in the quantity of input usage (Δz_i) are absolute changes in the quantities of inputs (i.e., $\Delta z_t = z_t - z_{t-1}$). Time ($T$) is an index representing each cross-section of the sample.

3.6.3 Sample at a Glance

Some descriptive statistics of the data set concerning the *pre* and *post* regulation periods are presented in Table 3.1 below. All values reported are adjusted for inflation, where appropriate, using the relevant price indices, namely the U.S. coal price index and the U.S. GDP deflator.

[51] In Christensen *et al.* (1980), it was calculated using the 1.5 diminishing value method, assigning 33 years of economic life for utilities.

[52] Miller and Modigliani (1966) have found that for the electric utility industry, Moody's Industrial Bond Yield is far superior to a weighted average yield on bonds.

Table 3.1

Some Descriptive Statistics [53] of the Sample

ANNUAL AVERAGE	VARIABLE	MEAN	ST. DEV.	MINIMUM	MAXIMUM
1985-89	Cost of Production ($ millions)	84.785	78.830	1.9276	427.00
	Output (MW millions)	3.8733	4.0003	0.0328	21.690
	Price of Coal ($ per ton)	36.84	7.95	19.87	68.99
	Price of Capital (user cost per $)	0.1009	0.0090	0.0927	0.1178
	Rate of Discount (real *r*)	0.0959	0.0074	0.0911	0.1106
	Capital Stock ($ millions)	196.03	208.13	8.1627	950.00
	Quantity of Coal (tons)	1680.0	1702.3	16.00	8455.0
1990-94	Cost of Production ($ millions)	90.179	87.042	1.8784	490.00
	Output (MW millions)	4.0562	4.2642	0.0277	21.883
	Price of Coal ($ per ton)	34.60	8.052	13.02	57.69
	Price of Capital (user cost per $)	0.0853	0.0087	0.0727	0.0983
	Rate of Discount (real *r*)	0.0819	0.0070	0.0714	0.0919
	Capital Stock ($ millions)	220.95	219.90	8.3468	1020.00
	Quantity of Coal (tons)	1707.6	1765.5	10.00	8570.0

[53] A more detailed *year-to-year* version of these statistics is presented in Table 4 of Appendix I.

3.7 Estimation Results

The dual system consisting of the cost function (3.24) [54] and the cost share equation (3.25) has been estimated using Zellner's Non-Linear Iterative Seemingly Unrelated Regression (NLISUR) method. [55] For ease of reference, we have reproduced the complete dual system (i.e., cost function [56] and cost share equations together) below.

[54] There is a debate among scholars, particularly those studying the behaviour of electric utilities, as to how the *output* variable is to be treated, i.e., as *exogenous* or *endogenous*, in econometric models. Due to the nature of regulation under which electric utilities operate, most economists (for example, Barbera and McConnell, 1990 and Rose *et al.*, 1992) argue that it is necessary to treat output as exogenous. In part, their argument is based on the fact that, in reality, regulators offer very little freedom to utilities to adjust output frequently, rather they successfully manipulate the output of each utility through regulation. However, some economists (for example, Atkinson & Halvorsen, 1998) argue that the production decisions of utilities have been changed in recent years, and that currently utilities have more freedom to make their own decisions on output. Thus, it is necessary to treat output as endogenous. After a careful consideration of both viewpoints, we decided to follow the former, by treating output as an exogenous variable in our econometric model. In part, the complications that arise when trying to model output as an endogenous variable, and the negligible effect that the latter approach has on the issue in hand, led to favouring of the former approach. A detailed discussion of this issue is presented in Appendix II.

[55] Zellner's Non-Linear Iterative Seemingly Unrelated Regression (see Zellner, 1962) estimates are obtained by estimating a set of nonlinear equations with cross-equation constraints imposed, but with a diagonal covariance matrix of the disturbances across equations. These parameter estimates are used to form a consistent estimate of the covariance matrix of the disturbances, which is used as a weighting matrix when the model is re-estimated in order to obtain new values of the parameters. These estimates are consistent and asymptotically normal, and, under some conditions, asymptotically more efficient than the single equation estimates. The seemingly unrelated regression method is a special case of generalized least squares with a residual covariance matrix of a particular structure: $V = S \otimes I_T$. This procedure is often referred to as Zellner's method, since it was originally proposed for linear models by Arnold Zellner, or also as the Aitken estimator (which is a special case).

[56] In early stages of this research, a suggestion was made that we should decompose our data set into two components to coincide with the *pre-regulation* (1985-90) and the *post-regulation* (1991-94) periods and run two separate regressions without including the *regulation-dummy* variable in the cost function. It was proposed that an appropriate test (for example, the Wald test) could be used to examine whether there has been any 'structural break' in the early 1990s, supposedly due to the CAAA. We considered this scenario and computed the appropriate Wald statistic following the procedure outlined in the Limdep 7.0 Manual on pp. 137-43. We rejected the hypothesis that: *CAAA have significantly affected the cost of producing electricity in the United States*, which is consistent with the corresponding results obtained with the relevant dummy variable. The regression and test results are presented in Table 2 in Appendix II.

Cost Function

$$\ln C=\alpha_0+\alpha_Q\ln Q+\alpha_1\ln(k_1P_1)+(1-\alpha_1)\ln(k_2P_2)+\gamma_1D_1+\alpha_TT+\tfrac{1}{2}\beta_{QQ}(\ln Q)^2+\tfrac{1}{2}\beta_{TT}T^2$$
$$+\tfrac{1}{2}\beta_{11}\left[(\ln(k_1P_1))^2+(\ln(k_2P_2))^2\right]+\beta_{12}\ln(k_1P_1)\ln(k_2P_2)+\beta_{1Q}\ln Q\left[\ln(k_1P_1)-\ln(k_2P_2)\right] \quad \textbf{3.24}$$
$$+\beta_{1T}\ln(k_1P_1)T+\beta_{2T}\ln(k_2P_2)T+\beta_{QT}(\ln Q)T$$
$$+\ln$$
$$\left[k_1^{-1}\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(k_2P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)+k_2^{-1}\left((1-\alpha_1)+\beta_{12}\ln(k_1P_1)+\beta_{11}\ln(k_2P_2)-\beta_{1Q}\ln Q+\beta_{2T}T\right)\right]$$

Cost Share Equation

$$M_1=\frac{\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)}{\left(\alpha_1+\beta_{11}\ln(k_1P_1)+\beta_{12}\ln(P_2)+\beta_{1Q}\ln Q+\beta_{1T}T\right)+\left(1-\alpha_1+\beta_{12}\ln(k_1P_1)+\beta_{11}\ln(P_2)-\beta_{1Q}\ln Q+\beta_{2T}T\right)k_1} \quad \textbf{3.25}$$

Factor of Proportionality

$$k_{it}=\exp(\delta_{ir}r_t+\delta_{iz}\Delta z_{it}+\delta_{iT}T) \qquad \text{where } i=\text{coal, capital}$$

The estimated coefficients [57] are presented in Table 3.2 below.

[57] We attempted several combinations of *initial* parameter values to verify convergence of the model. It turned out that the model is converging to the same set of parameter values regardless of the initial values being assigned, implying stability of the model's structure. In addition, we also tested for heteroskedasticity (using Breusch *et al.*, 1979) across *ten cross-sections* of the data set, but could not find any evidence of its presence. We also adopted the new technique suggested by Anderson and Vahid (1998) to test for heteroskedasticity in the case of pooling the cross-sectional and time-series data. This method also confirmed that our estimates are not prone to heteroskedasticity. Going a step further, the regulation dummy (D_1) was redefined: a value of *zero* was assigned for the period from 1985-89 (as opposed to 1985-90) and the value 1 was assigned for the period 1990-94 (as opposed to 1991-94). The objective was to examine whether there has been any 'delayed effect' of the reforms accompanied by the CAAA, and to verify if such an effect, if any, is substantive enough to change the parameter estimates of the model. It is evident from these estimated parameter values presented in Table 1 of Appendix II that they are invariant to either definition of the regulation dummy.

Table 3.2

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Constant	α_0	14.436 (13.865)
Output	α_Q	-0.4385 (-2.5710)
Price of Coal	α_1	0.1684 (2.1660)
Rate of Discount	δ_r	3.3051 (2.0677)
Annual Change in Coal Usage	δ_{z1}	0.000275 (2.7631)
Time trend of Input Prices	δ_T	-0.0160 (-3.2771)
Regulation Dummy	δ_{reg}	0.0097 (0.48081)
Capacity Dummy	δ_{sz}	0.57844 (2.3421)
Regional Dummy 1 (MW)	δ_{mw}	4.8274 (7.8832)
Regional Dummy 2 (NE)	δ_{ne}	4.4134 (7.1819)
Regional Dummy 3 (SE)	δ_{se}	4.4205 (6.9715)
Quadratic Output	β_{QQ}	0.07733 (6.4181)
Quadratic Time Index	β_{TT}	0.00262 (1.6276)
Quadratic-Price Of Inputs	β_{11}	0.06076 (5.0655)
Cross-Price Of Inputs	β_{12}	0.00009 (0.00580)
Price of Coal And Output	β_{1Q}	0.03217 (6.1235)
Price of Coal And Time	β_{1T}	-0.00871 (-1.9731)
Price of Capital And Time	β_{2T}	-0.00034 (-2.04337)
Output and Time Index	β_{QT}	-0.00506 (-2.0164)
Index of Time	α_T	-0.03325 (-1.92875)
Utility-Specific Dummy 1 (Plant 1)	γ_1	0.2794 (1.1312)
Plant 2	γ_2	0.7697 (3.0904)

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Plant 3	γ_3	0.5235 (2.1229)
Plant 4	γ_4	0.5530 (1.8660)
Plant 5	γ_5	0.55594 (2.2159)
Plant 6	γ_6	0.37085 (1.5055)
Plant 7	γ_7	0.64558 (2.1801)
Plant 8	γ_8	0.32370 (1.3127)
Plant 9	γ_9	0.50775 (2.0589)
Plant 10	γ_{10}	0.071896 (0.32385)
Plant 11	γ_{11}	0.06068 (0.27648)
Plant 12	γ_{12}	0.0441 (0.23538)
Plant 13	γ_{13}	-0.02568 (-0.1376)
Plant 14	γ_{14}	-0.03051 (-0.13845)
Plant 15	γ_{15}	0.16049 (0.7309)
Plant 16	γ_{16}	0.3674 (1.9627)
Plant 17	γ_{17}	-0.6555 (-2.9661)
Plant 18	γ_{18}	0.7046 (3.7803)
Plant 19	γ_{19}	0.04166 (0.18966)
Plant 20	γ_{20}	-0.00379 (-0.02031)
Plant 21	γ_{21}	-0.10244 (-0.46535)
Plant 22	γ_{22}	-0.14807 (-0.66722)
Plant 23	γ_{23}	0.21745 (1.1673)
Plant 24	γ_{24}	0.95116 (5.0121)

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Plant 25	γ_{25}	0.32449 (1.7335)
Plant 26	γ_{26}	-0.02676 (-0.12197)
Plant 27	γ_{27}	-0.11487 (-0.52312)
Plant 28	γ_{28}	0.67191 (3.6023)
Plant 29	γ_{29}	0.44359 (2.3658)
Plant 30	γ_{30}	-0.27167 (-1.2377)
Plant 31	γ_{31}	0.59285 (3.1809)
Plant 32	γ_{32}	-0.37475 (-2.0020)
Plant 33	γ_{33}	-0.37540 (-2.0029)
Plant 34	γ_{34}	-0.53612 (-2.8698)
Plant 35	γ_{35}	-0.27566 (-1.4734)
Plant 36	γ_{36}	-0.007443 (-0.03966)
Plant 37	γ_{37}	-0.32457 (-1.0989)
Plant 38	γ_{38}	-0.02121 (-0.08608)
Plant 39	γ_{39}	0.67859 (2.2911)
Plant 40	γ_{40}	-1.0979 (-4.2396)
Plant 41	γ_{41}	0.82452 (2.7903)
Plant 42	γ_{42}	-0.28246 (-1.1415)
Plant 43	γ_{43}	-0.66063 (-2.6287)
Plant 44	γ_{44}	1.3912 (3.7022)
Plant 45	γ_{45}	1.0436 (2.7786)
Plant 46	γ_{46}	0.35642 (1.0041)

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Plant 47	γ_{47}	0.38946 (1.0962)
Plant 48	γ_{48}	0.04464 (0.23948)
Plant 49	γ_{49}	0.28207 (1.2636)
Plant 50	γ_{50}	0.43181 (2.3202)
Plant 51	γ_{51}	0.50780 (1.4290)
Plant 53	γ_{52}	0.34279 (0.96346)
Plant 54	γ_{53}	-0.04219 (-0.11865)
Plant 54	γ_{54}	0.46306 (1.2321)
Plant 55	γ_{55}	0.83105 (4.4431)
Plant 56	γ_{56}	0.10386 (0.55176)
Plant 57	γ_{57}	0.65130 (3.4890)
Plant 58	γ_{58}	0.78528 (4.1633)
Plant 59	γ_{59}	0.36071 (1.9340)
Plant 60	γ_{60}	0.10726 (0.57393)
Plant 61	γ_{61}	0.88329 (4.6701)
Plant 62	γ_{62}	0.50249 (2.6980)
Plant 63	γ_{63}	0.53604 (2.1766)
Plant 64	γ_{64}	0.17622 (0.71117)
Plant 65	γ_{65}	-0.59727 (-2.7144)
Plant 66	γ_{66}	-0.55821 (-2.5392)
Plant 67	γ_{67}	-0.76819 (-3.4797)
Plant 68	γ_{68}	-0.15836 (-0.7188)

* *t-values are in parentheses.*

3.8 Analysis of the Results

3.8.1 Evaluation of the Model

The estimated coefficients of the model, along with the relevant *t*-statistics, are shown in Table 3.2 above. It turns out that all parameter values lie within permissible magnitudes and meet their expected signs. Hence, they are consistent with economic theory. To verify if they are invariant to different 'starting values', we re-estimated the model with different combinations of *initial* values. Interestingly, the model converges to exactly the same set of parameter values given in Table 3.2, confirming the robustness of our coefficient estimates.

We also verified whether the structure of the model and the estimated coefficients meet all of the required technical conditions considered above. In particular, we checked for the regularity conditions namely, *monotonicity* and *concavity*. To satisfy monotonicity, estimates of shadow cost shares (3.22) should be positive. To satisfy concavity, the Hessian matrix (3.23) should be negative semi-definite. All 680 observations in the sample satisfied monotonicity. All but *six* observations satisfied concavity. In addition to providing statistical rigour to the model, these conditions together ensure that our inquiry into the effects of the CAAA on production cost, input demand, and scale economies of electric utilities is consistent with economic theory (Jorgenson & Fraumeni, 1982, and Daly & Rao, 1985), and is therefore empirically sound.

As anticipated, substantial variations were apparent across most of the cross-sections. It justifies our move to incorporate *utility-specific* dummy variables into the model. It turned out that 42 of the 68 utility-specific dummy variables are statistically significant.

3.8.2 Tests of Hypotheses

The results of the hypothesis tests are reported in Table 3.3 below. Unless otherwise stated, all tests are Wald tests with a significance level of 95%.

Table 3.3

A Summary of the Hypothesis Test Results

Hypothesis	Wald Statistic	χ^2 Critical Value ($\alpha = 0.05$)
Properties of Equilibrium		
- Full static equilibrium	25.8623	7.8147
- Dynamic equilibrium	12.7883	5.9915
- CAAA as a departure from static equilibrium	10.7395	3.8415
Production Characteristics		
- Homotheticty	37.4978	3.8415
- Homogeneity	41.1914	3.8415
Geographical Factors		
- Midwest *vs* Northeast	3.8671	3.8415
- Northeast *vs* Southeast	0.0003	3.8415
- Southeast *vs* Midwest	1.1773	3.8415
- No geographical effect	62.9727	7.8147
Scale Economies		
- Constant Returns	24.1256	11.0705
- Megawatt capacity of plants	5.4854	3.8415
Regulatory Effects		
- CAAA (with *definition 1*)	0.2312	3.8415
- CAAA (with *definition* 2)	0.3615	3.8415
Technological Change		
- Hicks' neutral	2.8781	5.9915
- No technological change	6.1167	5.9915

- *Properties of Equilibrium*

Equilibrium properties of the model are tested using <u>three</u> hypotheses namely, full static equilibrium (*SE*), dynamic equilibrium (*DE*), and the CAAA as a departure from static equilibrium (*ADE*). The *SE* hypothesis (3.28) is rejected. The relevant Wald statistic is 25.8623 against a critical χ^2 value of 7.8147. This result reaffirms a well-established fact that firms subject to regulation, regardless of its type, fail to minimize their costs of production, and that the marginal rates of substitution are no longer equal to the ratios of actual market prices. Thus the result justifies our move to incorporate shadow input prices into the translog cost function. The *DE* hypothesis (3.29) is also rejected with the computed Wald statistic of 12.7883 against a critical χ^2 value of 5.9915. It implies, therefore, that both the discount rate (r) and the annual changes in input consumption (Δz) may influence the cost of power generation. Together, they bring about a *divergence* between the actual and the static equilibrium quantities of inputs used by the utilities. Thus, in the case of electric utilities, we cannot reject the alternative hypothesis of dynamic equilibrium subject to internal costs of adjustment.

The importance of these findings is that they help us examine whether the divergence has in fact been caused by the CAAA. This is done by testing the *ADE* hypothesis. Interestingly, the *ADE* hypothesis is rejected with the computed Wald statistic of 10.7395 against a critical χ^2 value of 3.8415. It appears, therefore, that the CAAA have contributed to the divergence despite the fact that additional information is needed (because electric utilities are subject to several regulations simultaneously) in order to single out the extent to which the CAAA have caused such a divergence between the actual and the static equilibrium quantities of inputs. As argued by Carlson *et al.* (1998), this could result from the distortions of the cost minimizing ratios of inputs due to the *switching of inputs* (i.e., from high-sulfur coal to low-sulfur coal) by the affected utilities in attempting to comply with the new regulation.

- ***Production of Characteristics***

The hypothesis that the production technology used by electric utilities is *homothetic* (3.31) is rejected; the Wald statistic is 37.4978 against a critical χ^2 value of 3.8415. As a result, homogeneity, which is conditional upon the acceptance of homotheticity, is also rejected. The relevant Wald statistic is 41.1914 against a critical χ^2 value of 3.8415. These results reinforce our earlier assertion that the relevant translog cost function is non-homothetic. In general, however, these two technical conditions have a little economic content, except that they provide useful information concerning the technology being used in power generation.

- ***Geographical Factors***

To examine the role of geographical factors in power generation, we considered several hypotheses. The United States was divided into *three* regions namely, Midwest (*MW*), North East (*NE*) and Southeast (*SE*), and identified each utility as being located in one of these regions. The hypothesis that there is *no* difference in costs between '*MW and NE*', is rejected. The Wald statistic is 3.8671 against a critical χ^2 value of 3.8415. However, the other hypotheses that no difference in costs exists between '*NE* and *SE*', and '*SE* and *MW*' cannot be rejected; the computed Wald statistics are 0.0003 and 1.1773 respectively against a common critical χ^2 value of 3.8415. The joint hypothesis, that there is *no* overall effect of location factor on the cost of production, is also rejected with the computed Wald statistic of 62.9727 against a critical χ^2 value of 7.8147.

These results together imply that the cost of producing electricity could vary across regions. In particular, the relevant parameter values shown in Table 3.2 reveal that the *per-unit-cost* of electricity in the Midwest region is slightly higher than the rest of the country. [58] While this observation is important for our analysis in the next paper, where we use the Data Envelopment Analysis (*DEA*) to measure the production efficiency of these utilities, it also provides useful information for regulators who are concerned about the *state-specific* performance of the federal regulations such as the CAAA.

[58] Exploring *why* such a difference exists in the Midwest is beyond the scope of this paper.

- *Scale Economies*

The hypotheses that production technology exhibits *constant returns to scale* is rejected, because the relevant Wald statistic is 24.1256 against a critical χ^2 value of 11.0705. It turns out, therefore, that the technology being used for power generation should be one of either decreasing returns to scale, or of increasing returns to scale. Furthermore, our hypothesis that the size of the plant does *not* affect the cost of production is also rejected. The relevant Wald statistic is 5.4854 against a critical χ^2 value of 3.8415. This means that the megawatt capacity of plants also matters, causing the cost per unit of electricity to vary across utilities. These observations, as a whole, imply that the existing plant capacities and the scale characteristics of the technology could also influence the compliance strategies preferred by the utilities. This could be due to the fact that scale economies are reflected in the cost minimizing behaviour. [59] They effectively determine the ways in which a particular utility is going to comply with the CAAA. We will give further consideration to this issue later in the discussion.

- *Regulatory Effects (The Clean Air Act Amendments of 1990)*

The important hypothesis that the CAAA have affected the cost of power generation is rejected; the computed Wald statistic is 0.2312 against a critical χ^2 value of 3.8415. In other words, this study provides ***no*** significant evidence to support the view that the cost of producing electricity by coal-fuelled utilities has been affected by the new environmental regulation. At a glance, this result appears to be in contradiction to several earlier studies

[59] It is shown above that non-homotheticity of the cost function is determined by the magnitudes of the parameters β_{1Q} and β_{2Q} of our model. The effect of the coal price interacting with output is positive since $\beta_{1Q} > 0$, whereas the effect of the cost of capital interacting with output is negative $\beta_{2Q} < 0$. In general, positive (negative) values of β_{iQ} indicate that an increase in the corresponding input price leads to lower (higher) scale economies. However, in our case as the magnitudes of β_{1Q} and β_{2Q} cancel each other out, the net effect of price changes would not alter scale economies.

that investigated similar types of environmental regulation such as the first set of Amendments to the U.S. Clean Air Act enacted in 1970. One of the major conclusions of these earlier studies was that the environmental regulation had created an additional burden on the cost of power generation.

Nonetheless, a number of very recent empirical studies which examined the effects of a wide variety of market-based environmental regulation have found that most of those earlier studies had failed to account for *all* of the elements, as a whole, that are critical to the underlying benefits and costs. As a consequence, those early studies had grossly underestimated the overall effectiveness of market-based environmental regulation, particularly the SO_2 tradeable permits program accompanied by the CAAA. Among the most useful of the very recent studies are Gray and Shadbegian (2000), Heyes (1999), Berman and Bui (1998), and Albrecht (1998). [60]

As a whole, the findings of these studies provide substantial evidence to support that market-based environmental regulation, particularly tradeable permits programs, have the potential for bringing about both cost-effective and environmentally-appealing solutions to complex environmental problems. Since market-based regulation, particularly tradeable permits, provides incentives to firms to continually update and improve their abatement methods, productivity could actually increase under this type of regulation. It is essential, therefore, that *all* of the aspects be carefully taken into account when assessing the overall effectiveness of market-based regulation. In this context, the findings of this study appear to be consistent with the recent empirical literature, and hence, are a reflection of the *actual* behaviour of utilities which are trying to comply with the CAAA in the best possible way.

To add more flesh to this important finding, *two* definitions for the dummy variable representing the CAAA are considered. The idea is to examine the robustness of the

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[60] A detailed discussion of these studies will be provided in Section 4.5.2 of Chapter 4.

relevant parameter estimate. Because the CAAA came into effect in 1990, the dummy variable was defined to take on the value of *0* for the years 1985-1990 (inclusive) and the value of *1* for the years 1991-1994 (inclusive). Then, it is redefined as one taking on the value of *0* for the years 1985-1989 (inclusive) and *1* for the years 1990-1994 (inclusive). We estimated the complete model under each of these definitions and found that the estimation results are invariant to either definition. [61]

These findings, taken together, provide enough evidence to support the conclusion that the implementation of the CAAA has caused only a negligible impact on the cost of producing electricity by coal-fueled utilities in the United States. This argument, in turn, calls into question some of the results found by previous researchers. For example, Kendrick (1997) and Yaisawarng and Klein (1994) have argued that the CAAA exerted an additional burden on the cost of power generation, causing a decline in the overall productivity of the industry. However, this argument is flawed in that it completely ignores the technological progress that may have occurred as a consequence of the new regulation.

In contrast, our findings suggest that the pressure from the CAAA on the cost of production has been diluted, as the affected utilities were both able to simultaneously improve their existing technology and to contribute to higher productivity due to the cost economies that resulted. These improvements to the existing technology (innovations) seem to have resulted in lower emissions. The lower the emissions, the lower the cost of buying permits, or the lower the need for switching to more expensive inputs. Thus the technological improvements bring about a cost saving which could be considered as an increase in the overall cost-efficiency, notwithstanding the regulatory impact on the cost.

[61] It should be noted, however, that the coefficient estimates reported in Table 3.2 are based on the first definition of the dummy variable and for comparison purposes, the corresponding estimates under the second definition are reported in Table 1 of Appendix II.

The implication of this observation is that it favours the highly debated *Porter hypothesis* [62] which asserts that environmental regulation may lead to the use of new and more energy-efficient technologies, and thus, firms would be better off in the long run. One can further investigate the plausibility of the Porter Hypothesis by examining the technological parameters of this model.

- *Technological Change*

Our investigation into the technological characteristics in power generation involves several steps. To examine the *nature* of the technological change (*TC*), we have constructed three hypotheses which we discuss in this section. The b*ias* of *TC* towards input use and its *magnitude* will be considered in Section 8.3.

The hypothesis that the technological change is *Hicks' neutral* cannot be rejected. The computed Wald statistic is 2.8781 against a critical χ^2 value of 5.9915. The hypothesis that *no* technological progress has occurred is rejected. The relevant Wald statistic is 6.1167 against a critical χ^2 value of 5.9915. These findings together imply that the production technology used by the utilities has improved in the *Hicks' neutral* fashion during the period of our sample. In particular, the estimated coefficient of the index of time used as a

[62] There has been considerable debate among analysts that the increasing stringency of environmental regulation in the United States will put home-based industries at a competitive disadvantage in international markets (See for example, Bernard *et al.*, 2000). According to this view, the increased costs that accompany more stringent controls will mean that domestic firms must confront their competitors abroad while being subject to an "unfair" burden. This seemingly straightforward contention has recently been disputed by Michael Porter (1995) who claims that stringent regulations need not be a disadvantage, but rather they can actually work in favor of the domestic industry and enhance its competitive position in international markets. This view is often referred to as the *Porter Hypothesis*. Porter (1995) limits his claim to regulations that are outcome-oriented, instead of technology specific, and which thereby provide the flexibility to encourage firms to seek out new technologies as a means of compliance with new regulations, such as the CAAA. Even though the electric utility industry does not directly compete with foreign firms, the *Porter hypothesis* is significant for this industry to the extent that the United States imports part of its electricity needs from Canada, where the environmental regulation is perhaps less stringent, as compared to the USA. However, exploring such an issue is beyond the scope of this paper, and thus, we simply search for some evidence that helps us support or refute the *Porter Hypothesis* based on the empirical results. Interested reader can consult Albrecht (1998) and Xepapadeas (1999).

proxy for the technological change (see Table 3.2) shows that the average improvement in technology is about 3% per year during this period, or put differently, the utilities have been able to achieve a cost-efficiency of about 3% per year. Thus, once again, we find that the CAAA have induced utilities to organize power generation more efficiently.

A somewhat puzzling question concerns why utilities fail to achieve this improvement in technology in the absence of any regulation such as the CAAA. A couple of plausible explanations can be offered. First, it has been argued that there is a *gaming* aspect (i.e. strategic behaviour) to environmental regulation that is largely ignored by the earlier studies, and that utilities may attempt to pre-empt regulators from choosing a higher technology standard by introducing new abatement technologies for adoption. This practice may be used by a utility for at least two reasons: (a) to reduce the uncertainty of future, possibly more stringent, regulations, and (b) to impose costs on existing competitors or on entrants. This argument presumes that the incumbent utilities, as well as their competitors, are all subject to the same type of regulation, which is consistent with the CAAA. Thus, even if the technology is productivity enhancing, the capital costs associated with the new technology may be high, and this may prevent other utilities from voluntarily adopting that technology.

One other explanation can be offered based on the option theory of investment. We see that utilities face two types of regulatory uncertainty: uncertainty regarding future regulatory levels of stringency, and uncertainty regarding the efficacy of 'undiscovered' abatement technologies. Since abatement capital costs are high, the utilities would prefer to wait as long as possible before making any abatement investment. Since it is more advantageous to be a follower rather than a leader in the adoption of abatement technology, this means that the required rate of return on their abatement investment would have to be 'large' enough to compensate them for the additional uncertainty that they face. So, if they believe that the existing regulations (those in effect prior to the passage of the CAAA) are not the 'most stringent' regulation to implement, they may wait to see how successful the new abatement technology is, before adopting it themselves, provided that the technology proves to be productive enough, and that it results in a high enough rate of return.

Thus, the findings of this study cast doubts on the commonly held view that the productivity of the electric utility industry in the United States has been adversely affected by the passage of the CAAA. On the contrary, it seems that there are two facets to the likely impact of the new regulation. First is our earlier finding that there has not been any significant effect of the new regulation on the cost of power generation. Second is the recorded gain in cost-efficiency of about 3% per annum. These two findings together imply that the *net* effect of the CAAA on productivity might have been positive, in spite of earlier studies which indicated the contrary. [63] While these results are consistent with the latest research findings cited above, one will have a clearer picture once if the other aspects of the observed technological progress and the scale economies were explored. This is the task of the next section.

3.8.3 Non-Parametric Tests of Technology and Scale Economies

To examine the nature of *input-bias* in the recorded progress in power generating technology, we considered the measure, τ, given by (3.36) above. It turns out that both of the relevant parameters β_{1T} and β_{2T} are negative, implying that the technological progress made during the period is *input-saving*. This means that the optimal *input-mix* used prior to the regulation has been changed, either in response to the new regulation, or due to fact that the achieved progress in technology has necessitated more energy-efficient ways to use

[63] A similar observation has been made in modern labour economics literature, contrasting the conventional view that regulations, in general, lead to inefficient outcomes. In particular, the very recent research into minimum wages has revealed that the new regulatory provisions governing minimum wages have, in some cases, led to more employment and a higher labour productivity in fast-food sector in the United States. For details, see Card and Krueger (1995).

inputs, particularly in the case of coal. Although it is not easy to find with certainty which factor is primarily responsible for the change, this observation confirms that the utilities have undoubtedly benefited from the change, for it is *input-saving*. This outcome can be considered a secondary economic effect of the CAAA.

Next, the recorded technical progress was decomposed into *three* components in order to examine its *bias* towards input use. The computed statistics are presented in Table 3.4. To make the comparison easier, the relevant measures have been calculated separately for the pre-regulation (1985-89) and the post-regulation (1990-94) periods.

Table 3.4

Elements of Technological Progress

Type of Technological Change	Annual Average 1985-89	1990-94
pure	2.33 %	1.27 %
factor-biased	- 3.18 %	- 3.79 %
scale-augmenting	4.10 %	6.39 %
overall	3.25 %	3.87 %

As conjectured earlier, all elements of technological progress (*TP*) appear to be strong, significant, and show substantial variations between the two periods. Moreover, the breakdown of the *TP* presents a clearer picture as to how the overall progress of 3% has been achieved during the sample period. The *pure* component of the *TP* has declined from 2.33% to 1.27%. The *factor-biased* component shows an increasing trend with 3.18% and 3.79% respectively between the two periods. The *scale-augmenting* factor seems much higher during the *post-regulation* period, accounting for about 6.39% of the recorded *TP*, as opposed to 4.10% during the *pre-regulation* period. As a whole, the results show that the optimal scales of power plant operations have been changed by the regulation. Clearly, the technology used by the utilities exhibits varying degrees of scale and the 'optimal scales' of power generation appear to have 'moved' to the regions of increasing returns in response to the new regulation. The results also show that the average annual progress in technology prior to the regulation, i.e., 3.25%, has increased during the post-regulation period up to 3.87%, implying that the pace of innovative activity has been higher after the regulation, perhaps as a result of the new limits set on the permissible emissions.

Furthermore, the exploration of scale economies is useful for any empirical analysis, particularly those trying to infer technological characteristics from the available information on cost of production. For this reason, the knowledge of scale characteristics of the utilities should facilitate our inquiry into production technology and the corresponding compliance strategies of the affected utilities. The scale economies typically measure the relative changes in output when the cost of production changes, while input prices are being held constant. They are sometimes expressed as reciprocals of cost elasticities with respect to output. In Table 3.5, we present the elasticity of output along with the corresponding measure of the scale economies for each of the periods.

Table 3.5

Scales of Operation

Measure	Annual Average	
	1985-89	1990-94
Elasticity of Output	0.6104	0.6031
Scale Economies	0.3895	0.3968

It is evident that the estimated average scale elasticity measure has roughly remained constant around 0.6 for the entire period of the sample. The fact that it is less than unity, suggests that the underlying technology exhibits increasing returns to scale.

3.8.4 Factor Substitution Possibilities and the CAAA

The Allen and Morishima partial elasticities of substitution (the averages for each period over the entire sample) are presented in Table 3.6.

Table 3.6

Measures of Input Substitution

Elasticities of Substitution	Annual Averages 1985-89	1990-94
Allen Measures		
ε_{11}	- 1.2925	- 1.6278
ε_{12} †	1.0012	1.0015
ε_{22}	- 2.3057	- 2.4156
Morishima Measures		
ξ_{12}	0.8322	0.7986
ξ_{21}	0.7166	0.6981

† *By symmetry* $\varepsilon_{12} = \varepsilon_{21}$.

Recall that the Allen elasticity measures account for the responsiveness of one input to changes in the price of another input, whereas the Morishima elasticity measures approximate the responsiveness of the *ratio* of the demands for two inputs to a change in the price of one input.

The results shown in Table 3.6 predict a certain degree of substitutability between capital and coal used by the utilities. This is clear from the computed Allen measures of elasticities. [64] Thus, it turns out that the new regulation, by making coal usage more expensive (because every unit of coal burnt increases the number of permits required) for

[64] The fact that own-price elasticities of demand are all negative implies that the model is consistent with economic theory.

the utilities, has induced a higher use of capital being substituted for coal in power generation. In other words, an incentive has been created among the affected utilities to move towards more environmentally-friendly (i.e., less polluting) technologies. This result [65] is consistent with our earlier finding that the optimal *input-mix* has changed after the CAAA were enacted. Morishima measures, on the other hand, reinforce these results by showing that the demands for inputs, i.e., coal and capital, are highly responsive to changes in prices.

3.9 Concluding Remarks

Using a generalized cost function, this chapter modeled and analyzed the production cost structure of the coal-fuelled electric utility industry in the United States. The primary task of this chapter was to examine the *cost aspects* of the SO_2 emissions trading program, which accompanied the CAAA. A secondary objective of this research was to single out the effects of this regulation on utility productivity, scale of operations, and more importantly, to shed light on the technological change induced by the CAAA. In order to facilitate the empirical inquiry into these issues, the analysis was centered on an econometric framework, which was supported by a panel data set covering the production activities of the leading U.S. electric utilities. The results of this study help draw the following broad conclusions.

Contrary to the views held by some previous researchers, who examined the impacts of environmental regulations, including the 1970 and 1990 Amendments to the U. S. Clean Air Act, this study finds ***no*** significant evidence to believe that the passage of the CAAA has increased the cost of power generation by the coal-fuelled electric utilities in the United States. Nonetheless, it was evident from the observed changes in the optimal input mix,

[65] The findings of Newell *et al.* (1998) who examined how regulation-induced innovation leads to energy-saving technological change are also consistent with this result.

that the new regulation, i.e., CAAA has caused some distortions to the profit-maximizing behaviour of these utilities. Such changes might have been triggered by the exercised options for compliance.

It was also evident from the underlying parameter estimates, that these utilities have been able to achieve substantial efficiency gains in power generation during the post-1990 period. Thus, it seems that the likely pressure of the CAAA, if any, on the cost of power generation would have been offset by these efficiency gains achieved through the technological improvements. Since such gains are instantly reflected in costs, it appears that the *net* effect of the CAAA on production cost should, on the whole, have been favourable to the industry.

This study also provides a number of insights for policy makers, particularly those responsible for federal regulations. For example, the finding that the cost per unit of electricity varies across states, and that the installed capacities of power generating plants influence the compliance strategies would provide guidance in designing both socially and economically efficient market-based policies in the future.

As a whole, the econometric analysis of the impacts of CAAA contained in this chapter will help to shed light on the general nature of the interactions between the CAAA and the power generation activity of the coal-fueled electric utilities in the United States. More importantly, these findings will guide us in the next chapter (Chapter 4), where linear programming techniques are combined with econometric methods to explore *efficiency aspects* of the CAAA.

MARKET-BASED ENVIRONMENTAL REGULATION AND FIRM EFFICIENCY: AN APPLICATION OF DEA AND TOBIT ANALYSIS

4

"Efficiency is concerned with doing things right: Effectiveness is doing the right things."

Peter F. Drucker
Management: Tasks, Responsibilities, Practices
Harper & Row, New York, 1974.

JEL Classification: C14; C34; D21; L51; Q28

4.1 Introduction

Economists have long been advocating the use of market-based instruments for protecting the environment. They argue that the absence of well-defined property rights gives rise to most environmental problems (Dales, 1968), and they often recommend the use of a market for trading environmental rights as a cost-effective way to achieve regulatory objectives. However, such arguments were largely neglected by regulators until the U. S. government decided to enact several Amendments to the Clean Air Act in 1990 (hereafter the CAAA). The CAAA [1] endorsed the establishment of a market for trading emission rights, and the federal Environmental Protection Agency (EPA) was entrusted with the task of monitoring the consequences of new measures.

The primary target of the CAAA was the U. S. electric power industry, whose hundreds of coal-fueled utilities were responsible for most of the emissions of criteria air pollutants [2] in the country. In 1997, they accounted for 57% of the nation's production of

[1] The CAAA consist of two Phases, namely Phase I and Phase II. See Appendix IV for details.
[2] The U.S. EPA has identified six criteria pollutants, namely sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter of 10 microns or less (PM_{10}), ozone (O_3), and Lead (Pb).

electricity, while contributing about 70% of the SO_2, 30% of the NO_x, and 35% of the CO_2 of the total emissions from all sources of air pollution in the United States. [3] To cope with the burgeoning problem, the CAAA called for each utility to adhere to a pre-specified limit of emissions. Any emissions above this limit required the utility to purchase additional permits. [4] In addition to buying permits, several other options were also available to the utilities for complying with the new regulation, namely investing in pollution abatement equipment (e.g., scrubbers), improving existing power generation technologies, adopting new technologies, and/or adjusting output.

When the CAAA were first enacted in 1990, many observers viewed them as an experiment to search for a cost-effective remedy for environmental problems. Now that several years have passed since their inception, analysts are trying to ascertain the effectiveness of the experiment. Some economists argue that the CAAA have led to an increase in the cost of electric power generation, and thus, caused a decline in the overall productivity of the electric utility industry. Their arguments are largely based on the observation that the annual average growth rate of 2% in the electric utility sector during the 1985-90 period slumped to 1% during the 1991-1996 period. [5] Given the annual average GDP growth of 2.5% which was steady throughout both periods, [6] and the annual average growth of 0.23% and 0.27% in the energy sector during the respective periods, [7] they claim that the decline in productivity is due to the adverse effects brought about by the CAAA. However, others maintain that the CAAA have indeed been successful as a cost-effective means of achieving environmental objectives, and that they stimulated the introduction of new 'environmentally-friendly' technologies for power generation. Their

[3] Annual Report, Energy Information Administration (1997) (http://www.eia.doe.gov).
[4] Presently, one permit permits one ton of emissions.
[5] U.S. Department of Energy, Annual Report (1997) (http://www.doe.gov).
[6] Congressional Budget Office (1997) (http://www.cbo.gov).
[7] Energy Outlook (1997) (http://www.doe.gov).

arguments are based on the latest EPA statistics of the recorded cost savings in monitoring, and the lower aggregate emission levels attained following the passage of the CAAA.

It appears, however, that all the arguments made above are largely based on casual observation, and that they lack theoretical or empirical justification. Thus, it is essential that one looks into the facts more formally before passing any judgment on the actual effects of the new regulation on the electric utility industry in the United States. As advocates of the CAAA, economists have a special role to play in determining whether their prescriptions have in fact been effective, and whether the anticipated gains have been realized. In particular, it is essential to examine the ways in which the CAAA have affected the production *efficiency* of these utilities. The term efficiency, in this context, refers to *productivity gains* emanating from lower per-unit-costs of power generation. These gains may result from improvements to existing technology, use of new technologies, and/or efficient allocation of inputs, all of which are potential secondary effects of the CAAA.

The measures of efficiency bear a particular significance in any formal study attempting to examine the actual impact on the affected utilities. On the one hand, if production efficiency has been hampered, then the potential gains of the CAAA, such as lower cost of enforcement and fewer emissions, have to be discounted against the loss in efficiency. On the other hand, if the new regulation has led to a higher level of efficiency in those utilities (in addition to the other benefits), then the potential gains should be added to the net efficiency gain accrued from the CAAA. In either case, therefore, efficiency gains should be accounted for when assessing the overall effectiveness of the CAAA.

Moreover, the present study can effectively be used to assess the plausibility of the highly debated *Porter Hypothesis*, which claims that stringent environmental regulations such as the CAAA, can actually work in favour of industries, by encouraging firms to seek out new technologies as a means of compliance. In particular, the study will help determine if the firms' incentive to innovate has grown through the establishment of a market for permits that provided them with the freedom to choose between permits and other means of abatement in order to comply with the regulation.

In the literature, a handful of studies have examined some aspects of the *first* Clean Air Act Amendments that came into effect in 1970. The thrust of these Amendments was to create an incentive for electric utilities to substitute low-sulfur coal for high-sulfur coal in their power plants. [8] In an early study, Atkinson and Halvorsen (1976) present evidence that the 1970 Amendments have, by encouraging the use of lower sulfur coal content, led to an increase in the cost of production. Kendrick (1997) argues that investing in abatement capital equipment (e.g., scrubbers) typically draws resources away from the production of other goods and services, affecting the productivity of 'goods' production. Barbera and McConnel (1990) claim that restricting SO_2 emissions had reduced the rate of productivity growth of electric utilities between 10% to 20% per annum in the 1970s. Among the few studies examining the CAAA, Yaisawarng and Klein (1994) find that there was a slowdown in the productivity of the U. S. electric utilities in the early 1990s. Winebrake *et al.* (1995) find that the CAAA adversely affected the electric utility sector, because the costs of compliance had added to the cost of producing electricity.

However, none of these studies undertook a formal inquiry into the effects of the CAAA on the *production efficiency* of the utilities. Perhaps, limitations on data and apparent complexities [9] associated with modeling electric utilities have prevented analysts from examining the issue more formally. Therefore, there exists a gap in the literature as to how one could account for efficiency effects brought about by the CAAA. It is this observation which motivated this study. The use of the linear programming technique known as the Data Envelopment Analysis (DEA), to examine the efficiency effects of the CAAA on the U.S. electric utility industry, will contribute to the literature in two ways.

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[8] See Blair (1973) for details of the Clean Air Act Amendments of 1970.

[9] The fact that electric utilities are subject to several regulations simultaneously is one such complexity that restricts analysts' ability to model cost minimizing behaviour under perfect market conditions.

First, it will extend the scope of the previous studies by undertaking a theoretical and empirical inquiry into the efficiency aspects of the utility regulation. Second, it will allow us empirically to estimate the relevant efficiency measures by using a new panel data set spanning a ten-year period (1985 through 1994) and covering 68 leading electric utilities operating in the United States.

The rest of the paper is organized as follows. Following the introduction, in Section 4.2, the DEA methodology and the concepts of efficiency are discussed. Section 4.3 presents the formal DEA model and describes the methods used in the calculations of the efficiency measures. The sources of data and the procedures adopted are discussed in Section 4.4. Section 4.5 presents the empirical results, and finally, Section 4.6 provides a summary of the major findings.

4.2 Data Envelopment Analysis (DEA) and the Concepts of Efficiency

4.2.1 What is DEA ?

Data Envelopment Analysis (DEA) [10] is a technique being used to explore efficiency aspects of production activities. It is an empirical tool based on linear programming methods, designed for estimating non-parametric *efficiency frontiers* under conditions of multiple inputs and outputs (Charnes *et al.*, 1994). The efficiency frontiers estimated represent the maximum output attainable from each input level and are depicted by linear *piece-wise* (i.e., curves made up of linear segments) loci based on input/output combinations attained by firms. The efficiency measures are defined in terms of deviations from the frontiers, and, for a given firm, they depend on the characteristics of the linear

[10] Pioneering work by Farrell (1957) laid the foundation for *DEA*, which is often referred to as *activity analysis*. Further research by Fare *et al.* (1983, 1986 and 1996) led to the development of a wide range of powerful DEA techniques which are frequently used by modern scholars. For good discussions of the modern economic applications of the DEA, see Cooper *et al.* (2000) and Coelli *et al.* (1998).

function that is selected (Ali *et al.*, 1995). Thus, the efficiency measures of the DEA refer directly to an individual firm's performance, rather than to population averages. For this reason, the DEA is particularly useful in this study because it allows us to estimate the magnitudes of (in)efficiency for each utility (or plant) by direct calculations. A single aggregate performance measure for each utility can then be established through systematic comparisons to quantitatively similar (reference) utilities. The fact that the DEA measures of efficiency compare individual utilities to reference plants on the frontier means that they are based on revealed *best practice*, [11] rather than on central tendency estimates, as in statistical analyses. The measures also include plant-specific estimates for desired changes in inputs or outputs (costs) for projecting inefficient plants on the efficiency frontier. As such, the DEA techniques operationalizes the concept of production efficiency developed in economics (Farrell, 1957), and they provide the analyst with techniques that facilitate the econometric estimation of production frontiers (Greene, 1993).

The DEA approach has been adopted by some scholars to examine a wide array of characteristics of energy production facilities (Fare *et al.*, 1996). Nonetheless, this study is the first attempt use this approach to examine the efficiency effects brought about by the CAAA in a framework where DEA methodology is combined with econometric methods (*Chapter 3*) to facilitate a comprehensive inquiry. In this study, the focus is on efficiency gains or losses resulting from the joint production of electricity (*good*) and emissions (*bad*). The emphasis is on the problem of measuring efficiency in the context of a firm producing a single output (i.e., electricity) using several inputs (i.e., capital and coal). The term *efficiency* refers to the conversion mechanism of physical inputs, such as capital and fuel, into outputs, and is defined as the degree to which the observed use of resources to

[11] A firm is said be a *best practice* firm (or efficient, for that matter) if it operates *on* the production frontier. Thus, firms which do not operate on the frontiers are considered inefficient. The term *best practice* refers to the set of management and work practices that results in the highest potential, or optimal, quantity of output for a given quantity and combination of inputs, i.e., productivity.

produce output of a given quality matches the optimal use of resources to produce the same output with the given quality.

4.2.2 DEA Concepts of Efficiency [12]

Three primal measures of efficiency are considered namely, *technical efficiency*, *allocative efficiency*, and *economic efficiency*, where the measure of economic efficiency is the product of the other two measures. It is assumed that the technology used in power generation is one with constant returns to scale (*CRS*). Later in the analysis, this assumption is relaxed by allowing for variable returns to scale (*VRS*) technology, in which case the technical efficiency measure is split into two other components, namely *scale* and *pure technical* efficiency.

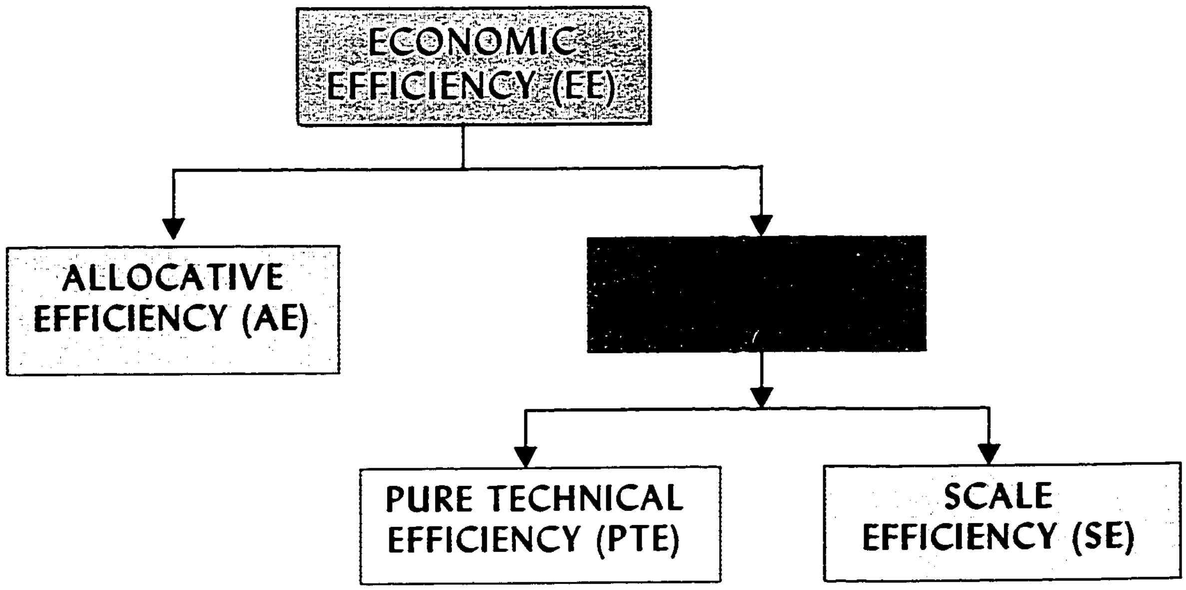

Figure 4.1: Structure of the Efficiency Measures

[12] This section has benefitted from Cooper *et al.* (2000), Coelli *et al.* (1998), and Kumbhakar (1992, 1993a, and 1993b).

As depicted in Figure 4.1, the economic efficiency (*EE*) measure is composed of two generic measures of efficiency, namely technical efficiency (*TE*) and allocative efficiency (*AE*). The technical efficiency measure is defined as the difference between the observed ratio of combined quantities of the firm's output to input and the ratio achieved by *best practice* firm in the industry (Cooper *et al.*, (2000), Coelli *et al.*, 1998). The allocative efficiency*(AE)* measure shows, for any level of production, whether inputs are used in the proportion which minimizes the cost of production, given input prices. In the case where 'variable returns to scale' technology is allowed the *TE* measure is split into two other components namely, *scale* efficiency (SE) and *non-scale* efficiency or *pure technical* efficiency *(PTE)*.

The *SE* measure reflects the extent to which an organization can take advantage of returns to scale by altering its size towards optimal scale, which is defined as the region where the relationship between outputs and inputs is characterized by constant returns to scale. The measure of non-scale technical efficiency estimates the proportion of technical efficiency which cannot be attributed to divergences from the optimal scale (scale efficiency). It is sometimes referred to as managerial efficiency or pure technical efficiency (Kumbhakar, 1993a). It should be noted that both of these measures are independent of prices and costs. Finally, the central measure, *economic efficiency* [13] refers to a production process where a firm is both *technically* and *allocatively* efficient, and thus, produces a given quantity, quality, and mix of outputs at a minimum possible cost, given the existing production technology. The efficiency measures considered above can best be described with the aid of a simple diagram as in Figure 4.2.

Figure 4.2 depicts the case where a utility is using two inputs, namely capital (x_1), and coal (x_2), to produce electricity (y). It is assumed that its production technology is characterized by 'constant returns to scale'. The isoquant labeled '*II*' is a unit isoquant

[13] The *economic efficiency* measure is sometimes called *cost efficiency* in the DEA literature.

representing the *fully efficient production*. It is also the locus of points requiring the 'lowest possible' amount of each input to produce one unit of electricity (say one kwh). If a utility is operating on this isoquant to produce one kwh, that firm is referred to as a *fully efficient firm*, whereas if the utility uses the input bundle denoted by *M* to produce the same amount of output, the *technical* inefficiency of its production is given the distance *LM*. In other words, it is the amount by which all inputs can be proportionally reduced without a reduction in output (*y*).

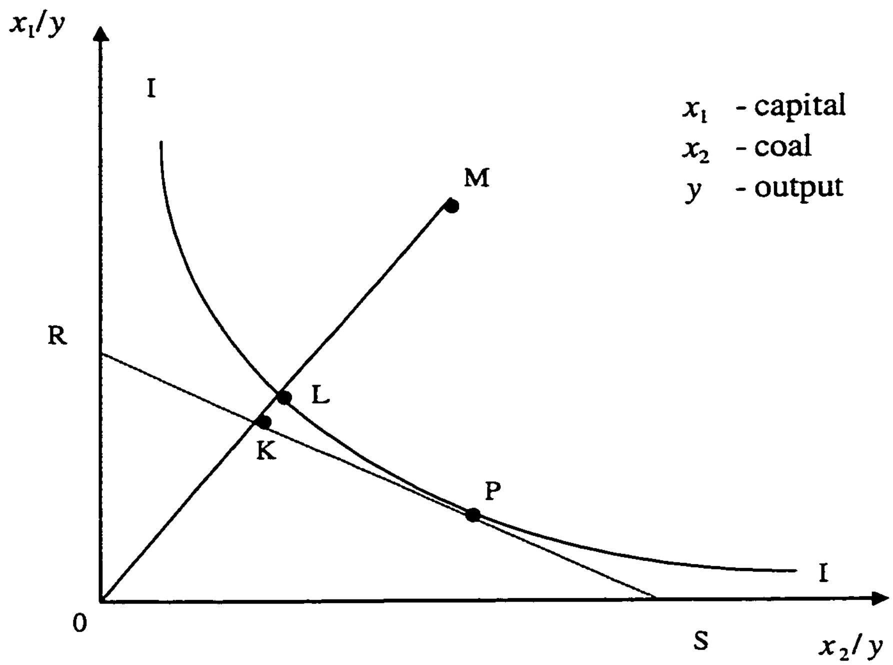

Figure 4.2: Graphical Illustration of the Efficiency Measures

In the DEA literature, the degree of inefficiency is typically expressed as a *ratio* or as a *percentage*. Thus, the technical inefficiency measure should be expressed as the ratio $LM/0M$, which demonstrates the percentage by which all inputs should be reduced to accomplish technically efficient production.

Formally, the measure of *technical efficiency* (*TE*) can be written as:

$$TE_i = \frac{0L}{0M} \qquad 4.1$$

which, by construction, is equal to $1 - \frac{LM}{0M}$.[14]

It is easy to see that all numerical values resulting from (4.1) are bounded by *zero* and *one*. The values measure the degree of technical inefficiency of each utility, where a value of *one* indicates that a utility is fully technically efficient, and the input-mix lies on the isoquant. In other words, then the utility is operating at a point such as L in Figure 4.2.

A careful examination of the *technical efficiency* (*TE*) measure reveals that it essentially captures under-utilization of inputs by the utility, i.e., inefficiency resulting from operating in the interior, instead of on the boundary, of the isoquant. Since point M in Figure 4.2 (where the utility is assumed to be operating) is clearly interior to the unit-isoquant, measuring *TE* is equivalent to determining whether the observed inputs yield the maximum obtainable output, i.e., whether individual observations are 'efficient' relative to the given technology. Hence, the *TE* measure enables us to compute the percent by which output can be increased, given the observed inputs of the particular observation. In other words, it allows one to determine the ratio of actual output to 'potential' or efficient output, where 'efficient' output is defined as 1.0 minus the ratio of observed to potential output (i.e., $1 - \frac{LM}{0M}$).

The second measure of efficiency is *allocative efficiency* (*AE*). Using the data on input prices, it is possible to compute the input price ratio given by the iso-cost line (*RS*). Then it will be possible to examine whether a particular utility is allocatively efficient or, put differently, whether that utility is operating at a point such as P in Figure 4.2.

Formally the *allocative efficiency* (*AE*) measure for this utility can be defined as:

[14] The subscript *i* denotes that the technical efficiency measure is *input-oriented*. A similar diagram can also be constructed in input/output space, and the resulting measure would then be called *output-oriented*.

$$AE_i = \frac{0K}{0L} \tag{4.2}$$

Notice that the distance *KL* is the reduction in production costs that would occur if production were to take place at the allocatively (and technically) efficient point *P*, instead of at the technically efficient, but allocatively inefficient point *L*. Thus, the measure *AE* given by the ratio (0K/0L) verifies whether a utility has chosen its input mix (for a given level of output and input prices) to minimize the cost of production (i.e., electricity), assuming that the utility being examined is already fully technically efficient. Like *TE*, the measure *AE* denoted by this ratio verges upon a value of 1.0, when the utility's chosen mix of inputs is cost minimizing.

In Figure 2, the *economic efficiency* (*EE*) measure is given by:

$$EE_i = \frac{0K}{0M} \tag{4.3}$$

where the reduction in cost of production is given by the distance *KM*. Notice that the measure *EE* can alternatively be defined as the ratio between the minimum cost and the total actual cost, where the product of *technical* and *allocative* efficiency measures gives us the *economic efficiency* measure:

$$TE_i * AE_i = \frac{0K}{0M} = EE_i \tag{4.4}$$

A utility will be economically efficient only if it is both technically and allocatively efficient. Thus a utility whose economic efficiency score (ratio) is 1.0, has achieved 100% efficiency in production.

Finally, consider the measures of *scale efficiency* (*SE*) and *pure technical efficiency* (*PTE*). *SE* refers to the scale of operations, and shows the extent to which a utility can adjust its scale by altering its size towards *optimal scale*, where optimal scale is defined as the region in which production technology is characterized by constant returns to scale. Thus, the measure *SE* is defined only when the production technology exhibits *variable returns to scale*. This shows the potential of DEA for identifying the true scale of operations of each utility. Furthermore, the DEA techniques can be used to decompose the measure *TE* into two parts (i.e., *SE* and *PTE*), in cases where the optimal scale of operation is found to be either decreasing or increasing returns. [15]

4.3 Modelling and Empirical Estimation of Efficiency

The approach to explore efficiency aspects of the new market-based environmental regulation is centered on a linear programming method called Data Envelopment Analysis (*DEA*). The *DEA* techniques, in general, are being used in a variety of policy-oriented research. [16] In this study, the major advantage of the *DEA* is its potential for exploring the efficiency aspects of firms. Empirical studies based on the *DEA* techniques consider a set of case-specific non-parametric measures that are particularly useful in examining firm-specific variations *vis-à-vis* the relative performance of firms or an industry. The present study extends this convention by integrating the *DEA* (*primary model*) into an econometric framework (*secondary model*). The discussion proceeds in two stages. In the first stage, a number of efficiency measures will be computed under each of the *CRS* and *VRS* assumptions.

In the second stage, a Tobit model is constructed to further investigate the qualitative features embedded in the *DEA* efficiency scores. This approach is the first of its kind to study market-based environmental regulation. Moreover, this two-stage modelling procedure would suit the objectives of this study better in that the relative performance of each utility subjected to the CAAA can be judged not only on the basis of the computed

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[15] By construction, the *PTE* measure is equivalent to the difference between the *TE* and the *SE* measures.

[16] For example, see Perelman (1995) and Yunos *et al.* (1997).

efficiency scores, but also in terms of how they interact with other qualitative factors affecting the profit maximizing behaviour. [17]

4.3.1 The DEA Model [18]

To motivate the analysis, consider the U. S. electric utility industry as having N firms.[19] Suppose that each firm uses capital (x_1) and coal (x_2) to produce electricity (y) measured in kilowatt hours (KWh), and that all firms face a common price for capital, but a firm-specific price for coal in the market. [20] To begin with, assume that the production technology of this industry is characterized by *CRS* technology.

Let the inputs for the i^{th} utility be represented by a column vector X_i, and the output by a scalar y_i. Also, let $2*N$ input matrix be $\boldsymbol{X}$, and the output vector Y for the industry. Now define the DEA_{CRS} model for the U. S. electric utility industry as:

$$\begin{aligned} &\min_{\theta,\lambda} \ \theta \\ &\text{subject to} \\ &-y_i + Y\lambda \geq 0 \\ &\theta x_i - X\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \qquad 4.5$$

where θ is a scalar, and λ is a $N*1$ vector of constants. The value of θ obtained will be the efficiency score for the i^{th} utility in the industry. It will satisfy the condition: $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence, a technically-efficient firm. As noted before, the *CRS* assumption is appropriate only when the utilities are operating at an

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[17] Grafton *et al.* (1999) employed a similar procedure to address efficiency issues in fisheries.
[18] This section draws from Coelli *et al.* (1998) and Kumbhakar (1993a and 1993b).
[19] In the DEA literature, firms are sometimes referred to as Decision Making Units (*DMUs*).
[20] The assumption that coal price is utility specific corresponds to the actual beahviour of the firms in the energy sector. In practice, each utility has contractual agreements with the supplier, and thus, the quoted prices of coal vary accordingly.

optimal scale. Thus, in cases where industry-specific characteristics, such as imperfect competition or constraints on investment, cause utilities to deviate from their optimal scale, the DEA estimation under the *CRS* assumption results in measures of technical efficiency which are confounded by *scale* efficiencies. In such circumstances, the technology used by the industry should be considered as one exhibiting *VRS*. To account for *VRS*, the DEA_{CRS} model in (4.5) should be modified, by adding the convexity constraint, $N1'\lambda = 1$.

$$
\begin{aligned}
&\min_{\theta,\lambda} \ \theta \\
&\text{subject to} \\
&-y_i + Y\lambda \geq 0 \\
&\theta x_i - X\lambda \geq 0 \\
&N1'\lambda = 1 \\
&\lambda \geq 0
\end{aligned}
\qquad 4.6
$$

The presence of the convexity constraint (i.e., $N1'\lambda = 1$) in (4.6) guarantees that any inefficient utility is compared *only* against counterparts that are of similar size. In other words, the projected coordinates (for a particular utility) on the *DEA* frontier will be a *convex* combination of observed firms. Since this convexity restriction is not present in the *CRS* case, utilities may not be distinguishable *vis-à-vis* their *size* (i.e., capacity of plants). Thus the constraint is necessary to add rigour to the *DEA* model under the *VRS* assumption.

The empirical analysis begins with the assumption of *CRS* technology, and *three* (primal) measures of efficiency, namely *technical efficiency*, *allocative efficiency* and *economic efficiency*, will be calculated for the entire sample. Then, assuming *VRS* technology, a scale efficiency measure for each utility is derived by estimating both the DEA_{CRS} and the DEA_{VRS} models simultaneously. The technical efficiency measure obtained under the *CRS* assumption will then be decomposed into two components, namely *scale* *efficiency* and *pure technical efficiency*. If the technical efficiency measure is found to be different between DEA_{CRS} and DEA_{VRS} for any of the utilities, it indicates that the technology used by that particular utility is subject to scale (in)efficiency where the degree of scale (in)efficiency is equal to the difference between the two measures.

4.3.2 The Econometric Model

It is possible sometimes that the efficiency scores estimated by the DEA model are influenced by other utility-specific characteristics. Cases in point are location, ownership differences (i.e., public *vs* private), scale characteristics, and various government regulations. These factors which are *qualitative* in nature, and typically exogenous to production activities of the utilities, affect the profit maximizing behaviour of firms, and thus, they are reflected in the production strategies of utilities. [21] Thus, it is essential to extend this analysis beyond the scope of the DEA model in order to account for such effects. This will help strengthen the inquiry of this study in *two* ways. First, with the use of an appropriate econometric model, it is possible to verify whether the computed efficiency scores are dependent upon any of the qualitative factors. Second, the econometric results may provide a guide to policy makers who are concerned with the efficiency aspects of regulation.

The *Tobit* model [22] seems particularly suited to the issue in hand. Because the efficiency scores to be represented by the limited dependent variable are continuous and bounded by zero and one, and the explanatory variables of the model are represented by a set of binary variables, the Tobit model provides a convenient framework for analyzing the

[21] See Atkinson & Halvorsen (1986), Platt & Welch (1989), Singh (1991), and Kumbhakar (1996).

[22] In the literature, there is an alternative type of models called the *Market Response Models* (*MRM*) which are sometimes being used in cases where the dependent variable is strictly non-negative (e.g., sales). However, in this case, the Tobit model was found to be more appropriate since all of the explanatory variables are dichotomous (i.e., dummy variables) in nature, and vary between *0* and *1*. For an excellent review of the MRM, see Hanssens *et al.* (1990).

effects of the qualitative factors on the electric utility industry in the United States. The Tobit model also enables one to construct several standard hypotheses (to be discussed below) to asses the extent(s) of such effect(s). [23]

A few technical aspects of the Tobit model are worth considering. Tobit models with limited dependent variables are classified into two general categories as *censored* and *truncated* models. These categories are defined on the basis of whether or not the values of explanatory variables for the missing dependent variable data are known. In general, a censored sample refers to a data set in which some observations of the dependent variable, corresponding to known values of the independent variable(s), are not observable, whereas a truncated sample refers to a data set in which the values of the independent variable(s) are known only when the dependent variable is observed. As such, the series of efficiency scores representing the dependent variable in the Tobit model do not directly fall into either category, because the data set does not have any missing observations either for the independent variable(s) or the dependent variable. In contrast, a series which is bounded (or censored at) by *zero* and *one* exists. Hence, the dependent variable has to be truncated at **0** from below (the lower bound) and **1** from above (the upper bound) in the estimation. Following the practice of economists who have dealt with similar situations, the series of *efficiency scores* will be considered as censored samples. [24]

One other technical issue is whether a *fixed* or *random* effects structure would be more appropriate for the Tobit model chosen for our purpose. A common formulation of the *fixed* effects model assumes that the intercept varies across cross-sectional units and/or across time periods. In contrast, the *random* effects models are based on an overall intercept and on an error term consisting of *two* components where one is the traditional

[23] For an excellent discussion of dummy variables in the context of Tobit models, see Maddala (1987).
[24] For excellent discussions of the theoretical arguments governing Tobit models, see Amemiya (1985, Chapter 10), Green (1993), and Kennedy (1992).

error term unique to each observation, and the other is an error term representing the extent to which the intercept of the ith cross-sectional unit differs from the overall intercept.

Several arguments exist in the literature which facilitate the choice of appropriate structure for Tobit models. In spite of the fact that most of the arguments are *ad hoc*, and offer very little guidance on the '*right*' choice of the structure, it appears that there is some agreement among economists that a random effects structure is more appropriate for models with qualitative and limited dependent variables. Since the panel data set used in this study has ten cross-sectional units, it is possible to save many degrees of freedom if only the mean and variance were estimated using a random effect model. Moreover, if inferences were to be made about the population from which these cross-sectional data came, it has been shown that random effects models (as compared to fixed effects models) are more appropriate (Kennedy, 1992). Confirming Kennedy's view, Maddala (1987, p. 335) notes that "All in all, estimation of random effects models appears to be more advantageous". Furthermore, since some time-invariant observations exist in our data set (such as installed capacity and location), the Tobit model with random effects structure appears to be more appropriate for the present study (Hausman *et al.*, 1981).

Hausman (1978) proposes a test which can effectively be used to facilitate the choice under specific circumstances. A test statistic, known as the *Hausman statistic*, is computed using the estimated coefficients and the variance-covariance matrices resulting from two regressions, one run under the assumption of *fixed* effects and the other under the assumption of *random* effects. The null hypothesis (H_0): 'random effects structure is appropriate' is tested using the Hausman statistic which is distributed as chi-square with one degree of freedom. This test is used to facilitate the choice made in the present study. The Hausman test results (see Table 6 of Appendix IV) imply that the null hypothesis (H_0) cannot be rejected for *any* of the regressions in the Tobit model. Hence, the appropriate model shall be the one with a random effects structure, where the limited dependent variable (i.e., the efficiency score) is truncated at *0* and *1* (i.e., the lower and upper bounds respectively).

To conclude the discussion on technical aspects of the Tobit model, it is worth considering the circumstances under which a *constant* term should be appended to a Tobit regression. [25] In cases where a particular qualitative variable is represented by *two* separate dummy variables in the Tobit model (say, for example, two separate dummies corresponding to the pre-regulation period and post-regulation period), **no** constant term should be included in order to prevent the estimation procedure from breaking down, since such 'dual' dummy variables together form a unit vector. In all other cases, where each qualitative variable is represented by a *single* dummy variable, a constant term should be appended to the regressions. Since all of the Tobit regressions belong to the latter, a constant term is included in the regressions. [26]

A number of qualitative variables are considered. First is the *size* of the utility as measured in installed megawatt capacity. For the entire sample, a median value for the installed capacity of the industry is established, and, is used to distinguish utilities as *small* (below median) and *large* (above median), where the relevant dummy variable takes on the value of **0** and **1** respectively. Second, a *regulation* dummy is introduced to capture the effects of the CAAA on the overall economic efficiency of utilities. The relevant dummy takes on the value of *0* for years 1985 through 1989 and *1* for years 1990 through 1994. An interaction dummy variable which is defined as the product of the *size* of the utility and the regulation dummy is also considered. The aim is to investigate whether the effects of the CAAA vary across *small* and *large* utilities. [27]

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[25] One other important exception with respect to Tobit models is that it is sometimes possible that the log-likelihood function is positive (Greene, 1995, page *x*).

[26] For details, see Maddala (1987) and Kennedy (1992).

[27] In addition, the entire data set of 68 utilities was grouped into *three* regions, namely Mid West (42), South East (18), and North East (08), and separate dummy variables representing each region were also included in the regressions. However, because of their poor performance in the estimation (i.e., insignificant coefficient estimates) such dummies have been omitted from the regressions.

The Tobit model which incorporates all of these qualitative variables [28] consists of four regressions. It can be written formally as:

$$y_i^* = \beta' X_i + \varepsilon_i$$
$$y_i = y_i^* \quad \text{if} \quad 0 < y_i^* \leq 1 \qquad 4.7$$

By expanding (4.7), the *four* regressions of the Tobit model could be derived:

$$TE = \delta_{TE}^1 + \delta_{sz}^1(size) + \delta_{rg}^1(re) + \delta_{sr}^1(size{*}reg) \qquad 4.7a$$

$$AE = \delta_{AE}^2 + \delta_{sz}^2(size) + \delta_{rg}^2(re) + \delta_{sr}^2(size{*}reg) \qquad 4.7b$$

$$SE = \delta_{SE}^3 + \delta_{sz}^3(size) + \delta_{rg}^3(re) + \delta_{sr}^3(size{*}reg) \qquad 4.7c$$

$$EE = \delta_{EE}^4 + \delta_{sz}^4(size) + \delta_{rg}^4(re) + \delta_{sr}^4(size{*}reg) \qquad 4.7d$$

where *TE* is technical efficiency, *AE* is allocative efficiency, *SE* is scale efficiency, and *EE* is economic efficiency.

4.4 Sources of Data

The primary data set used in this study is from the Federal Energy Regulatory Commission (FERC), the national institution which oversees the federal regulation governing the electric utility industry in the United States. The FERC has established a number of standard forms used to collect data from *coal-fired* electric utilities on a monthly as well as an annual basis. Most of the data are from the *FERC Form 1*, [29] the mandatory

[28] In the early stages of this research, a suggestion was made that GDP per capita should also be included as an explanatory variable in the Tobit model. This possibility has been explored very carefully. It was found that such a variable cannot be considered when the model consists of a dependent variable which is truncated between *0* and *1* while all other explanatory variables are (qualitative) dummy variables (Maddala, 1987). One way to overcome this difficulty is to translate GDP per capita into an index varying within *0* and *1*. See Appendix IV for details.

[29] A specimen of the FERC Form No. 1 is attached to Appendix I.

annual report submitted by coal-fired electric utilities. The sample includes cost and production data [30] for 68 leading coal-fueled U. S. electric utilities over a ten-year period, from 1985 to 1994. [31] Since these data are used to examine the effects of the CAAA, it is expected that the time period chosen will be sufficient to undertake meaningful comparisons between pre- and post-regulatory periods, and to assess the effectiveness of the CAAA. [32] Summary statistics of the sample are presented in Table 4.1 below.

Table 4.1

Summary Statistics of the Sample

ANNUAL AVERAGE	VARIABLE	MEAN	ST. DEV.	MINIMUM	MAXIMUM
1985-89	Cost of Production ($ millions)	84.785	78.830	1.9276	427.00
	Output (MW millions) (y)	3.8733	4.0003	0.0328	21.690
	Price of Coal ($ per ton)	36.84	7.95	19.87	68.99
	Price of Capital (user cost per $)	0.1009	0.0090	0.0927	0.1178
	Rate of Discount (real *r*)	0.0959	0.0074	0.0911	0.1106
	Capital Stock ($ millions) (x_1)	196.03	208.13	8.1627	950.00
	Quantity of Coal (tons) (x_2)	1680.0	1702.3	16.00	8455.0
1990-94	Cost of Production ($ millions)	90.179	87.042	1.8784	490.00
	Output (MW millions) (y)	4.0562	4.2642	0.0277	21.883
	Price of Coal ($ per ton)	34.60	8.052	13.02	57.69
	Price of Capital (user cost per $)	0.0853	0.0087	0.0727	0.0983
	Rate of Discount (real *r*)	0.0819	0.0070	0.0714	0.0919
	Capital Stock ($ millions) (x_1)	220.95	219.90	8.3468	1020.00
	Quantity of Coal (tons) (x_2)	1707.6	1765.5	10.00	8570.0

[30] A detailed discussion of the data set is provided in the Appendix I.

[31] Budget limitations have precluded from extending the data set beyond 1994.

[32] Some of the most recent studies examining the U.S. acid rain program (Schmalensee, *et al.*, 1998, Joskow, *et al.*, 1998, and Burtraw, 1999) find that the utilities which were affected by the CAAA had started responding to the new environmental measures as early as 1991 despite the fact that Phase I of the CAAA had been scheduled to begin in 1995. These studies further show that such behaviour is consistent with both the intertemporal optimization and the long-term nature of the investment contracts agreed upon by the utilities. Thus, it is believed that the data set is broad enough to shed light on the behaviour of the electric utilities affected by the CAAA.

The estimation of the DEA model requires *five* data series: output, capital, coal, price of capital, and price of coal. Output is the net generation of electricity measured in millions of kilowatt hours. Capital input is measured in terms of installed megawatt capacity of each utility, while coal input represents actual usage of coal adjusted for British thermal units (Btu) content. Price of capital is the *user cost of capital*, calculated using a formula developed by Jorgenson (1963) and Coen (1968): $P_k = \frac{g(\delta + s)(1 - uB)}{(1 - u)}$, where g is cost per unit of capital, δ is economic rate of depreciation, s is rate of return on investment, u is corporate income tax rate, and B is the present value of tax depreciation allowed for every dollar's worth of investment, i.e., $B = \sum_{t=1}^{\infty} d_t(1 + s)^{-t}$. As a proxy for q, the 'Handy-Whitman Price Index' will be used, which is compiled from the Moody's Nation Wide Survey of Public Utility Progress. Following Christensen *et al.* (1980), d = 0.045 was calculated by using the 1.5 diminishing value method given a 33-year economic life for plants. Moody's Industrial Bond Yield [33] was used as a proxy for the rate of return on investment (s). Following Coen (1968), the useful life of a utility for *tax* purposes (l) was taken as 18 years. Furthermore, it was assumed that the government has allowed utilities to write off their plant(s) in 18 years, by equal installments. Price of coal is the *f.o.b.* price per ton of coal paid by each utility.

4.5 Empirical Results

4.5.1 The DEA Model

The DEA_{CRS} model (4.5) was estimated and the *technical*, *allocative* and *economic* efficiency measures were obtained for <u>all</u> 68 utilities for each year covering the entire sample. The efficiency scores are presented of Table 2 in Appendix IV. Under the

[33] Miller and Modigliani (1966) have found that for the electric utility industry, Moody's Industrial Bond Yield is far superior to a weighted average yield on bonds.

alternative assumption, the DEA_{VRS} model (4.6) was also estimated, and the scores of *scale efficiency* for each utility were obtained. These scale efficiency measures, along with the classification of each utility in terms of its verified scale of operation, namely constant-returns (*CRS*), increasing-returns (*IRS*), or decreasing returns to scale (*DRS*) are shown in Table 3 in Appendix IV.

Attempts were made to determine the role, if any, of geographical factors in the observed variations of production efficiency achieved by the utilities. The efficiency scores have been averaged across states, as well as within three regions, namely North-East, South-East, and Mid-West. The computed values are shown in Tables 4 and 5 (see Appendix IV). Next, the variations in scales of operation between the pre-regulation and the post-regulation periods were examined by grouping each utility according to its verified scale, namely *CRS*, *IRS*, or *DRS*. The details are shown in Table 2 of Appendix IV. To facilitate this analysis further, a number of Figures have been produced, which show variations in the relevant efficiency scores across regions, and between the 'pre-regulation' and the 'post-regulation' periods. These Figures are presented in Appendix IV.

The estimated efficiency scores, in general, suggest that the 'operating scales' of many utilities have been changed noticeably between 1989 (*prior to regulation*) and 1994 (*after the regulation*). For example, the total of 47% of the *IRS* utilities in 1989 has increased to 58% by 1994. In contrast, the 47% of all utilities which were operating at *DRS* in 1989, declined to a meager 9% by 1994, following the passage of the CAAA. As a result, the total number of utilities operating under *CRS* increased from 6% to 20% between 1989 and 1994. These findings together show that following the passage of the CAAA, most utilities have moved their production levels to 'regions' (i.e., segments of the production function) where the technology is characterized by either *IRS* or *DRS*.

Figure 1 in Appendix IV shows that both *technical* and *economic* efficiency scores recorded a substantial drop in 1987. This is true for all regions of the country. Since the drop had occurred before the CAAA, the real *GDP* growth rates for the mid-1980's were analyzed to examine whether they are consistent with the average growth rates of overall economy. The 'correlation coefficient' for the two series, namely real GDP growth and the average technical efficiency measure for the period 1985-1988, was 0.91. Thus, the drop in efficiency *may* well simply reflect the country's overall economic activity, but may not be due to any other factor peculiar to electric utility industry (See Figure 2 in Appendix IV). [34]

The averages of the efficiency scores over regions (Tables 4 and 5) together with the corresponding figures, suggest that the efficiency gains may be subject to geographical factors. This observation provides further support to the earlier finding in the econometrics paper that the location affects the cost of production, regulation notwithstanding. Furthermore, Figure 3 in Appendix IV shows that after 1991 there had been a downward pressure on all elements of efficiency with the exception of technical efficiency. One explanation could be that the CAAA would have caused such pressure, because there is no evidence of any other 'utility-related' event that had taken place in the early 1990s. In such a case, the CAAA seemed to have motivated the affected utilities to improve their existing technologies, or to invest in new methods of power generation. However, the slower pace in other efficiency scores, particularly after 1991, suggests that the gain in technical efficiency has come about with an additional cost.

4.5.2 Econometric Model

The regression results of the Tobit Model are presented in Table 4.2 below. Before interpreting the results, it should be noted that every 1% increase in the dependent variable implies that a utility could raise its output by 1%, given the same level of inputs, because the dependent variable of the Tobit Model is expressed in terms of efficiency.

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[34] This observation will be investigated further in Section 4.5.2 below, as the results of the *qualitative factors* of the Tobit model are analyzed.

To begin with, consider plant *size* or the capacity of the utilities. Recall the distinction in size, i.e., plants with a capacity of 665 MW (the median value of the industry) or more, are considered as *large*, while the rest, i.e., those below 665 MW are considered as *small*. This analysis shows that both the allocative and scale efficiency measures vary with the installed capacity of plants. In particular, it appears that when a utility is *large*, it is allocatively more efficient than a *small* one. In other words, the marginal rates of technical substitution (MRTS) in the case of *large* utilities are closer to the price ratio of inputs than are those of *small* utilities.

Table 4.2

Tobit Model Regression Results

	Limited Dependent Variable			
	Technical Efficiency (TE)	Allocative Efficiency (AE)	Scale Efficiency (SE)	Economic Efficiency (EE)
Constant	0.7809* (80.761)	0.8209* (21.623)	0.8925* (97.824)	0.5896* (46.797)
Plant Size (*large vs small*)	0.0006 (0.071)	0.0165* (4.060)	0.0561* (4.348)	0.0141 (1.392)
Regulation Dummy	0.0259* (2.755)	0.0639* (15.107)	0.0042 (0.0322)	0.0273* (2.731)
Size*Regulation Dummy	0.0248* (2.302)	- 0.0196* (2.933)	- 0.0072 (0.0394)	0.0053 (0.415)

Notes:
1. All explanatory variables are dummy variables.
2. Tobit model is truncated at both tails at 0 and 1.
3. *t-ratios* are in parentheses.
4. * indicates that the parameter estimate is statistically significant at 5%.
5. Results are generated using LIMDEP 7.

The relevant parameter estimate shows that utilities which are *large*, as opposed to which are *small*, could raise its output by approximately 1.6 % using the same level of inputs. [35] This implies that the technology used in power generation is characterized by

[35] This argument presumes that *large* utilities are able to adjust their output freely, other regulations notwithstanding.

variable return to scale (*VRS*). The *VRS* argument gains further strength from the estimated measure of scale efficiency, which implies that *large* utilities operating under *VRS* have the potential for increasing their output by about 5%, using the *same* level of inputs and by re-adjusting the scale of operations. Thus, it is possible that the plant *size* of a utility could lead to variable efficiency levels in the allocation of inputs and in the scale of operations.

Next, consider the key variable of the analysis, namely the *regulation dummy*. The relevant parameter estimates suggest that the passage of the CAAA has substantially affected the production efficiency in the U. S. electric utility industry. The estimated measures of *technical efficiency* (*TE*) are positively correlated with the regulation. Thus, it is evident that the CAAA have led to a substantial technical efficiency of about 2.5% in power generation in the United States. If put differently, this implies that the potential for, or net generation of coal-fuelled electricity has increased by about 2.5%, despite the stringent environmental measures brought about by the CAAA. Notably, this result stands in contradiction to similar findings of some previous studies, which emphasized that the environmental regulations, by and large, create an additional burden to the production cost, and thus, results in a negative effect on productivity.

However, as discussed below, very recent studies have challenged this view. [36] It has been argued that the *actual* costs of market-based environmental regulation had been grossly over-estimated in most previous studies, mainly due to their partial consideration of the underlying effects. These recent studies provide empirical evidence to demonstrate that, in reality, the net impact on production cost of the regulatory measures would indeed be negligible or in some cases, even favourable. Let's consider a few of these studies.

[36] A similar observation has been made in the modern labour economics literature, contrasting the conventional view that regulations, in general, lead to inefficient outcomes. In particular, the very recent research into minimum wages has revealed that the new regulatory provisions governing minimum wages have, in some cases, led to more employment and a higher production efficiency in the fast-food sector in the United States. For details, see Card *et al.* (1995).

Gray and Shadbegian (2000) examined the environmental regulation affecting the U.S. paper industry. They found that the choice of technology has been influenced by environmental regulation in such a way that paper plants had increasingly employed less polluting (or greener) technologies. In another study, Berman and Bui (1998) examined the oil refinery industry of Los Angeles, which is heavily regulated by air pollution regulation. Their objective was to determine the regulatory impact on refinery productivity. They discovered that the *gross* costs of environmental regulation in the industry are far greater than the *net* cost, as abatement has been productive. Their study casts doubts on some of the earlier studies, as they present evidence to show that during the post-regulation period (i.e., early 1990s), the productivity of the oil refinery industry has in fact been increased, and then has remained stable. Yet another study by Albrecht (1998) reveals that environmental regulations lead to improved competitiveness, particularly when regulation is linked to specific products. Heyes (1999) draws a similar conclusion based on his study that examined how environmental regulations can afford "secondary" benefits to firms through product design and corporate morale. Another somewhat earlier study by Jaffe *et al.* (1995) recognizes the need for taking into account all the benefits when assessing the costs of market-based environmental regulation, because such regulations induce utilities to be more efficient. If one were to generalize the implications of these studies, particularly those of Heyes (1999), Berman and Bui (1998), and Albrecht (1998), then an argument can be made in favour of the *Porter Hypothesis*, which postulates the long term benefits of environmental regulation. Moreover, these recent findings, as a whole, are consistent with the results of this study which explored the actual behaviour of the electric utilities in attempting to comply with the CAAA in the best possible way. [37]

[37] Recall the findings of the econometrics paper (Chapter 3), where the pure cost effects of the CAAA were found to be negligible, and that the per-unit-cost of producing electricity remained largely unaffected. The finding here confirms those earlier econometric results by showing that the regulation-induced pressures on cost, if any, have obviously been diluted by the gains in technical efficiency.

A similar but stronger argument can be made in favour of the effects of the CAAA on *allocative* efficiency of the affected utilities. The estimated parameter value suggests that there has been a positive effect of about 6% on *allocative* efficiency due to the CAAA. It appears that the CAAA have also induced utilities to use their inputs more effectively, thereby enabling them to achieve higher efficiency with the current level of inputs. Given the attributes of the CAAA and their likely impact on electric utilities, this result is not surprising. Some of the very recent investigations into this issue (for example, Carlson *et al.*, 1998) reveal that these affected utilities have adopted *fuel-switching* as the major option for compliance. Thus, the findings of this study are consistent with the observation of Carlson *et al.* (1998), and suggest that such a move has enabled utilities to find more efficient ways to mix their inputs, so that the increasing production cost, due to higher prices of low sulfur coal, is kept at a minimum. It is evident, therefore, that the attained improvement in *allocative* efficiency has brought about a positive impact on output. The important lesson to be learnt here is that it is essential that one takes into account all efficiency gains, and then weigh them against any unfavourable effects, before passing any judgment on the overall impact of the CAAA on electric utilities.

The interactive dummy variable (i.e., size*regulation) unveils yet another dimension of the CAAA. As for *technical efficiency*, the regression results confirmed that the effects of the new regulation vary across utilities, depending on the plant *size*. It is found that *large* utilities had the potential for increasing their output by about 2% using the same amount of inputs. Thus the production capacities owned by the utilities offer one explanation as to why the effects of the CAAA on production efficiency vary across utilities. It has also been found that *large* utilities have the potential for 'larger' gain in efficiency relative to *small* utilities. However, this finding suggests that small utilities are more efficient in allocating (mixing) inputs. Perhaps, the easier adaptability to different engineering standards may explain why small utilities have become allocatively more efficient in responding to the new regulatory measures.

To broaden the scope of this investigation, it has been looked into if the production activities of electric utilities displayed any observable pattern in the computed scores of efficiency, particularly after the passage of the CAAA. The data set, which spans a ten-year period, has been decomposed into two segments, 1985-89 and 1991-94. The annual average efficiency scores have been computed for each period across regions as well as states. These aggregate measures of efficiency are presented in Tables 3, 4 and 5, while the corresponding figures are founded in Appendix IV.

Table 4.3

Wald Tests Results for Regulatory Effects

Efficiency Measure	H_0 : pre-reg. period (1985-89) = post-reg. period (1990-94)	
	Wald Statistic	Reject H_0 (*Yes/No*)
Technical Efficiency (TE)	37.1439	Yes
Allocative Efficiency (AE)	60.0539	Yes
Economic Efficiency (EE)	41.4035	Yes
Scale Efficiency (SE)	16.0206	Yes

Notes:
1. All hypothesis tests are Wald tests where N = 680.
2. Degrees of freedom for *upper* and *lower* bounds are given by the number of equality restrictions plus one $(q + 1)$, and the number of equality and inequality restrictions (p) respectively. In this case, the *df* for both *lower* and *upper* bound critical values is equal to 4. For details see Kodde and Palm (1986).
3. Critical value at 5% level (taken from Table 1 of Kodde and Palm, 1986) is 10.384.

The Tables, together with the corresponding figures, show that the aggregate efficiency scores are subject to variations between the two periods. This observation has been proved by constructing a number of Wald tests. The resulting test statistics were compared with the critical *chi-square* values to test the null hypothesis (H_0) that: "the estimated efficiency scores are not significantly different between two time periods". The test [38] results are presented in Table 4.3.

It is interesting that the null hypothesis (H_0) cannot be rejected for any of the four cases. The implication is that the production activities of the U. S. electric utilities have been subject to regulatory effects brought about by the CAAA. In particular, the findings of this study suggest that such effects have been efficiency-enhancing. This observation is consistent with the findings in the econometrics paper (Chapter 3), indicating that the CAAA have had no significant effect on the cost of power generation. Furthermore, the scale efficiency measure displays a variation between the two periods, that reconfirms the earlier finding that the optimal scales of operation of these utilities have been changed significantly as a result of the CAAA. This observation, in turn, adds rigor to another argument made earlier as part of the DEA analysis, namely the detection of significant variations in efficiency measures after 1990.

4.6 Concluding Remarks

This chapter conducted an economic inquiry into the *efficiency aspects* of the regulated coal-fuelled electric utility industry in the United States. A number of efficiency measures were considered, namely the *technical*, *allocative*, *economic* and *scale* efficiency measures in order to determine whether the 1990 Amendments to the U.S. Clean Air Act have caused any significant effect on the production efficiency of this industry. The empirical analysis, based on *DEA* methodology and a Tobit model, offers some guidance as to *how* and *to what extent* such regulation may have affected this industry. The study provides a number of insights that are useful for regulators in assessing whether or not their policy objectives have been met.

[38] Construction of Wald tests for testing non-linear hypotheses are discussed in Lafontaine *et al.* (1986).

The study presents substantial evidence to suggest that the CAAA have affected the production efficiency of the U.S. electric utility industry. Even though the effects are mixed - some are adverse and others favourable - all in all, the CAAA, in addition to being a cost-effective alternative for achieving a cleaner environment, are proved to be *efficiency-enhancing*. In particular, the study finds that utilities have been successful in securing a substantial improvement in efficiency in power generation. As a result, the cost pressures that were alleged to have been generated as a result of the new regulation have been offset by the efficiency gains. Therefore, the findings of this study challenge the conventional view, particularly of those who conducted earlier studies, that environmental regulation always harms industry productivity, and therefore, it is thus counter-productive. Moreover, the findings of this study are consistent with those of the very recent literature, [39] and provide a basis for questioning the plausibility of those earlier studies which, in most cases, had been found inadequate in accounting for both the cost and efficiency aspects of the CAAA simultaneously.

Furthermore, our findings suggest that several *qualitative* factors such as 'size of plants' and 'regions where utilities are located' have been responsible, in part, for variable effects of the CAAA. Consequently, these effects have led to variations in efficiency potential across utilities, the federal guidelines governing the CAAA notwithstanding. Nonetheless, it appears that a substantial majority of utilities has attempted to overcome this problem, by altering the scales of operation.

Our major finding that any unfavorable effects of the CAAA, if any, on production cost are being offset by the simultaneous efficiency gain in the power generating production technology proves to be particularly interesting. According to our study, these gains in production efficiency are attributable to two major factors; (1) the changes in input mix, and (2) the induced-improvements to the existing technologies, or due to the use of

[39] See Section 4.5.2 for details.

new ones. In this context, the findings of this study provide some support for the *Porter Hypothesis*, which asserts that environmental regulation would be beneficial for firms in the long run. Thus, this analysis based on linear programming and econometric methods contributes to a key debate in the field of environmental regulation.

Before concluding the discussion, several limitations of the present study deserve mention. First, it should be noted that the *DEA* method and the data set employed in this study do not account for differences in the quality of inputs across plants. For example, *no* distinction was made between high- and low-sulfur coal, and no sufficient information on all capital equipment was available. Also, no readily usable data on pollution equipment such as scrubbers were available. Thus, the findings of this study may be improved by employing additional data that are useful to distinguish utilities further in terms of their individual characteristics.

CONCLUSION 5

*"The beginning of wisdom is: Acquire wisdom,
And with all your acquiring, get understanding."*

Proverbs 4:7

This dissertation contributes to an important debate in environmental policy: the role of market-based instruments in environmental protection. In particular, by focussing on tradeable permit programs, this research explored the potential of such programs to provide lasting solutions to environmental problems. Our empirical analysis is built on the central tenets of positive economic theory, and is supported by a comprehensive analysis based on econometric and linear programming techniques.

5.1 Lessons Learned

The political economy approach to market-based instruments introduced in the first paper (Chapter 2) helped us understand the significance of political and institutional factors on the *feasibility* of market-based policies. We also found how such factors influence the *performance* of public policies being implemented to achieve environmental objectives. The discussion of the central tenets of political economy unfolded a wide array of critical factors that affect the way environmental goals are set by policy makers. Moreover, we discovered how the institutional, regulatory and political factors interact with actual market conditions (i.e., markets with pre-existing distortions), affecting all stages of public policy formulation in democratic societies.

In the second paper (Chapter 3), we used a generalized cost function to model and analyze the production cost structure of the electric utility industry in the United States. The primary objective of this chapter was to assess the cost effectiveness of the new market-based environmental regulation enacted by the Amendments to the U. S. Clean Air

Act of 1990 (CAAA). A secondary objective of the study was to single out the effects of this regulation on utility productivity, scale of operations, and more importantly, the use of technological improvements induced by the regulation. To facilitate our investigation into these issues, we employed an econometric framework, and made use of a panel data set covering production activities of the leading U. S. electric utilities that came under the purview of the CAAA. This research leads to the following broad conclusions about the effects of this new regulation on the electric utility industry in the United States.

First, contrary to the views held by some previous researchers, we find *no* significant evidence to believe that the passage of the CAAA has created an additional burden to the cost of producing electricity by the coal-fired electric utilities in the United States. However, it was evident from the observed changes in the optimal input mix, that the new regulation has caused some distortions to the profit-maximizing behaviour of these utilities. Such changes might have been triggered by the exercised options for compliance.

Second, it was evident from the underlying parameter estimates, that the utilities have been able to achieve substantial gains in the efficiency of their production technologies during the post-regulation period. The findings imply that the likely pressure, if any, of the CAAA on the cost of electricity generation would have been surpassed by the productivity gains achieved through these technological improvements. Since these productivity gains are instantly reflected in costs, the *net* effect of the CAAA on production cost should have been favourable to the industry.

These findings proved to be particularly useful in examining the efficiency aspects of the CAAA, the task that we performed in the third paper (Chapter 4). In this research, the definition of efficiency included a number of important measures, namely *technical*, *allocative*, *economic* and *scale* efficiencies. Our goal was to examine whether the new environmental regulation has brought about any significant impact on the production efficiency of the electric utility industry. This component of our inquiry was based on the Data Envelopment Analysis (DEA) and the econometric methods. While our findings offer guidance as to how this new regulation has intervened the production technology, they also provide a number of insights that are useful for regulators in assessing whether or not their objectives have been met.

Our inquiry reveals that the CAAA have undoubtedly influenced the production efficiency of the U. S. electric utility industry through *changes* in technology. This was clearly evident from the relevant parameter estimates of the model. Even though the realized effects are mixed - some are adverse and others favourable - all in all, we find that the CAAA, in addition to being a viable alternative for achieving a cleaner environment, are proving to be *efficiency-enhancing*. Furthermore, we find that several qualitative factors such as *plant size* and *location* are important in understanding the post-regulation behaviour of many of these utilities. The relevant parameter estimates suggest that the effects of the CAAA at the micro-level have varied substantially due to these qualitative factors. Consequently, these effects have led to variations in efficiency across utilities, the federal guidelines governing the CAAA notwithstanding. In cases where cost pressures were imminent, a fairly large number of utilities have attempted to overcome such problems affecting efficiency, by adjusting their scales of operation.

We also find that utilities have been successful in attaining a substantial improvement in technological efficiency at the plant level. This gain has helped utilities to balance the cost pressures from the new regulation. Hence, our findings challenge the traditional view, particularly of those who conducted earlier studies, that environmental regulation always harms industry productivity, and is thus counter-productive. It is gratifying to note that our findings are consistent with those of the very latest research (for example, Berman & Bui, 1998 and Albrecht, 1998) and hence, provide a basis for questioning the plausibility of those earlier arguments. One shortcoming of these earlier studies appears to lie in their inappropriate accounting for efficiency effects induced by the CAAA. Often, they have examined only one aspect of this issue: *either* cost *or* efficiency. One implication of our finding is that unfavourable effects, if any, on production costs seem to be diluted by the efficiency gains attained on the technology side. This gain in efficiency results from improvements made to existing technologies and from the adoption of new ones.

As a corollary, our study provides some support for the *Porter Hypothesis*, which asserts that with environmental regulation, electric utilities are better off in the long run because the incentive to use new low-emission technologies would generate substantial efficiency gains, which are likely to outweigh the cost pressures brought about by the regulation. In this sense, our research unveils yet another new dimension in the debate of environmental regulation.

5.2 Policy Implications

Our research into the *cost* and *efficiency* aspects of the regulated electric utility industry in the United States provides a number of insights for policy makers. First, our finding of cost-per-unit variations in electricity across various regions in the United States, and the close affiliation of installed capacities of power generating plants with compliance strategies, should provide guidance for policy makers in shaping this policy for future applications, particularly those proposed for Canada. Another significant feature of our analysis is that we find *no* evidence to support the commonly held view that the newly introduced market-based regulation has adversely affected the productivity of the electric utility industry in the United States. This finding should help enhance confidence in future considerations of tradeable permit programs, not only in the United States, but also in other countries. In particular, this finding should prove comforting to policy makers and other experts in Canada who are currently engaged in debates over the possibilities of implementing tradeable permit programs in order to fulfil international commitments, such as the Kyoto Protocol.

More importantly, our finding that the overall impacts of the CAAA on power generation in the United States are two-fold, i.e., the *effects on cost*, and *the effects on efficiency*, should prove encouraging, because the failure to recognize the technological progress induced by the new regulation has led many previous researchers to conclude that the CAAA was ineffective or even counter-productive. It became apparent in our second approach to the tradeable permit programs based on the DEA and Tobit analysis that this reasoning was misleading. On the contrary, we found that most of the affected utilities, in attempting to comply with the regulation, were able to either improve the efficiency of their existing production technologies, or to adopt alternative environmentally-friendly technologies in power generation, or both. Overall, this dissertation presents strong evidence to support the concept that tradeable permit programs, if devised appropriately, can help provide sustainable solutions to many environmental problems.

5.3 Suggestions for Further Research

This study introduced a logical approach to assess the overall effectiveness of market-based regulations, particularly the emerging tradeable permits programs. Unlike most of the previous studies, the approach taken by this study involved a *simultaneous* inquiry into several critical elements of tradeable permits, namely the institutional, cost and efficiency aspects. This inquiry helped determine the role of each element which collectively influence environmental policy goals. Despite the fact that the findings offered overwhelming support for tradeable permit programs, this study should *not* be considered as advocating tradeable permits as the *ultimate* solution to *all* environmental problems. On the contrary, this study demonstrates the potential of market-based instruments for achieving both economically and socially efficient solutions to many environmental problems. Whether or not this potential is invariant to the unique circumstances of the environmental issue in hand, has yet to be examined. In particular, it is imperative to explore the virtues and pitfalls of tradeable permits systems when they are applied to different types of pollutants, and when they are implemented in conjunction with other market-based and non-market-based regulatory instruments.

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APPENDIX I

Data Sources, Definitions, and Summary Statistics

1. Introduction

The empirical analyses in Chapters 3 and 4 of this dissertation are based on the cost and production data relating to sixty eight of the largest coal-fueled electric plants located in the United States. The analysis covered a ten-year period, from 1985 to 1994. [1] The power plants included in the sample are a subset of the 110 largest emitters regulated under Phase I of the Amendments to the U.S. Clean Air Act of 1990 (CAAA). With respect to their ownership, fifty-three are investor-owned and fifteen are publicly-owned. Publicly owned plants include eight of the twelve 'dirtiest' plants (i.e., largest emitters) owned by the U.S. electric utility companies (http://www.epa.org). [2]

2. Sources of Data

Plant output (i.e., power generation), prices, inputs, installed capacity, and market values of boilers have been obtained from various publications of the Federal Energy Regulatory Commission (FERC). The FERC is the national institution overseeing the federal regulation governing the electric utility industry in the United States. A majority of the data series is from the ***FERC's Form 1*** [3] the mandatory annual report submitted by 'large-scale' coal-fuelled U.S. electric utilities. A utility is considered a 'large-scale' if it exceeds one million MWh of total annual sales, 100 MWh of annual sales for resale or 500 MWh of gross interchange out, or 500 MWh of *wheeling* for other utilities (http://www.ferc.fed.us).

The economic data including interest rates, sulfur intensities of coal, and other data relating to the U.S. electric power generation have been compiled from various publications of the U.S. General Accounting Office (http://www.gao.gov), the U.S. Department of Energy (http://www.doe.gov), the Energy Information Administration (http://www.eia.doe.gov) and the National Regulatory Research Institute of the State University of Ohio (http://www.nrri.ohio-state.edu). Discount rates and returns on utility investment are from the Annual Reports of the Moody's Nation Wide Survey of Public Utilities (http://www.moodys.com/). [4]

3. Targetted Utilities

The FERC data set consists of the following power generating plants.

Table 1

STATE	TARGETTED PLANT	PARENT COMPANY
Alabama	E. C. Gaston-5	Alabama Power Co
Florida	Big Bend	Tampa Electric Co
	Crist	Gulf Power Company
	Smith	Gulf Power Company
Georgia	Bowen	Georgia Power Co

1 The original data set covered 103 power plants regulated by the Amendments to the U.S. Clean Air Act of 1990. However, to avoid analytical problems and to create a balanced data set, the utilities with missing data were omitted.

2 In the United States, investor-owned utilities account for 76% of the total power generation, while publicly-owned utilities produce about 10% (http://www.eia.doe.gov).

3 A specimen of the FERC Form No. 1 is attached to this Appendix.

4 URLs for data sources are shown for information purposes only. Publications containing the data are available at the libraries of the University of Ottawa, Carleton University, and the National Research Council (NRC).

STATE	TARGETTED PLANT	PARENT COMPANY
	Hammond	Georgia Power Co
	J. McDonough	Georgia Power Co
	Wansley	Georgia Power Co
	Yates	Georgia Power Co
Illinois	Baldwin	Illinois Power Co
	Coffeen	Central Illinois Public Service Co
	Grand Tower	Central Illinois Public Service Co
	Hennepin	Illinois Power Co
	Joppa Steam	Electric Energy Inc.
	Kincaid	Commonwealth Edison Co
	Meredosia	Central Illinois Public Service Co
	Vermilion	Illinois Power Co
Indiana	Bailly	Northern Indiana Public Service Co
	Tanners Creek	Indiana & Michigan Electric Co
	Breed	Indiana and Michigan Electric Co
	Cayuga	Public Service Company of Indiana/ PSI
	Clifty Creek	Indiana-Kentucky Electric Corp
	F. B. Culley	Southern Indiana Gas and Electric Corp
	Gibson	Public Service Co of Indiana
	H. T. Pritchard	Indianapolis Power and Light Co
	Michigan City	Northern Indiana Public Service Co
	D. H. Mitchell	Northern Indiana Public Service Co
	R. M. Schahfer	Northern Indiana Public Ser. Co.
	Petersburg	Indianapolis Power and Light Co
	R. Gallagher	Public Service Company of Indiana/ PSI
	Wabash River	Public Service Company of Indiana/ PSI
Iowa	Burlington	Iowa Southern Utilities Co
	George Neal-3	Midwest Power Systems Inc
	Prairie Creek1-3	Iowa Electric L & P Co
	Prairie Creek-4	Iowa Electric L & P Co
	Riverside	Iowa-Illinois Gas and Electric Co
Kentucky	Reid	Big Rivers Electric Corp
	Coleman	Big Rivers Electric Corp
	E. W. Brown	Kentucky Utilities Co
	Pineville	Kentucky Utilities Co
	Ghent	Kentucky Utilities Co
	Green River	Kentucky Utilities Co
	Tyrone	Kentucky Utilities Co
Maryland	Chalk Point-1&2	Potomac Electric Power Co
	Wagner	Baltimore Gas and Electric Co
	C. P. Crane	Baltimore Gas and Electric Co
	Morgantown	Potomac Electric Power Co
Missouri	Asbury	The Empire District Electric Co
	Labadie	Union Electric Co

STATE	TARGETTED PLANT	PARENT COMPANY
	Sioux	Union Electric Co
New Jersey	B. L. England	Atlantic City Electric Co
	Deepwater	Atlantic City Electric Co
New York	Greenidge	NYSEG
	Milliken	NYSEG
Ohio	Conesville-1-3,5&6	Columbus Southern Power Co
	Edgewater	Ohio Edison Co
	Muskingum River	Ohio Power Co
	Gen J. M. Gavin	Ohio Power Co
	Kyger Creek	Ohio Valley Electric Corp
	Niles	Ohio Edison Co
	W. H. Sammis	Ohio Edison Co
	R. E. Burger	Ohio Edison Co
Tennessee	Allen	Duke Power Co
	Lee	Duke Power Co
Wisconsin	Edgewater-4	Wisconsin Power and Light
	LaCrosse Genoa-3	Dairyland Power Co-op
	Nelson Dewey-1&2	Wisconsin P&L
	Pulliam-Total	Wisconsin Public Service Corp

4. Sample Geography

Geographical distribution of power plants included in the sample is presented in Table 2.

Table 2

State	Number of Plants
Alabama	01
Florida	03
Georgia	05
Illinois	08
Indiana	14
Iowa	05
Kentucky	07
Maryland	04
Missouri	03
New Jersey	02
New York	02
Ohio	08
Tennessee	02
Wisconsin	04
TOTAL	**68**

5. Employed Data Series

The data series are discussed under three headings:

- **Series:** *Directly from Sample*
- **Series:** *Constructed*
- **Series:** *Secondary*

5.1 Series: *Directly from Sample*

- *Total Capacity of Plants*
  Denotes the maximum generation capacity of the plant(s) measured in Kilo Watt hours (KWh)

- *Net Power Generation*
  Output of the plant measured in KWh

- *Average Cost of Fuel per Unit Burned*
  Actual cost in dollars per short ton of coal

- *Average Cost of Fuel Burned per KWh*
  Ratio of the cost per ton of coal and the actual generation of electricity (KWh) per ton of coal.

- *Cost per KWh of Installed Capacity*
  The ratio between total cost of production and the total capacity of the plant in terms of KWh.

5.2 Series: *Constructed*

- *User Cost of Capital* (P_k)

  Cost of production is the cost of power generation. Output is given by the *net* generation of electricity ('000 of KWh). Price of coal is the delivered price (including the cost of transportation) per ton of coal at plant sites. The price of capital (i.e., implicit rental price) is computed using a method developed by Jorgenson (1963) and Coen (1968). [5] The *user cost of capital* (P_k) is $P_k = \left[g(\delta + s)(1 - uB)\right]/(1 - u)$ where g is cost per unit of capital, δ is economic rate of depreciation, s is the rate of return, u is the corporate income tax rate, and B is the present value of the tax depreciation allowed per one dollar investment: $B = \sum_{t=1}^{\infty} d_t(1 + s)^{-t}$.

[5] See Jorgenson, D.W. (1963), "Capital Theory and Investment Behavior," *American Economic Review*, 53(2), Papers and Proceedings of the Seventy-Fifth Annual Meeting of the American Economic Association, May, pp. 247-259; and Coen, R.M. (1968), "Effects of Tax Policy on Investment in Manufacturing," *American Economic Review*, 58(2), Papers and Proceedings of the Eightieth Annual Meeting of the American Economic Association, May, pp. 200-211.

- *Cost per unit of Capital(g)*

  'Handy-Whitman Price Index' was taken from the Annual Reports of the *Moody's Nation Wide Survey of Public Utility Progress* of the United States.

- *Rates of Depreciation (d)*

  d = 0.045 was adopted from Christensen *et al.* (1980) [6] where it was calculated using the diminishing value method, assigning 33 years of economic life for power plants.

- *Rates of of Return on Utility Investment (s)*

  'Moody's Industrial Bond Yield' is used as a proxy. It was taken from the *Annual Reports of the Moody's Nation Wide Survey of Public Utility Progress* of the United States.

- *Life of a utility (l)*

  Following Coen (1968), the useful life of a utility for tax purposes (l) was taken to be18 years, and it was assumed that governments allow utilities to write off the power plant(s) in 18 years, by equal installments.

5.3 Series: *Secondary*

Data series in nominal terms have been converted to real terms using the following indices:

- GDP Deflator
- Coal Price Index

6. The CAAA and the Forward-Looking Behaviour of Electric Utilities

Recent studies [7] examining the U.S. emissions trading program find that the utilities affected by the CAAA had started responding to the new environmental measures immediately following the passage of the CAAA, despite the fact that Phase I was scheduled to begin in 1995. This behaviour is clearly evident from Table 3 below, which shows that the utilities had already mitigated their emissions by about 45% (as compared to the Phase I targets) by the time the CAAA went into effect in 1995. The observed behaviour which is consistent with economic theory is a reflection of both the inter-temporal optimization and the long-term contractual commitments on utility investment. This observation has been confirmed by the latest EPA information (see http://www.epa.gov) shows that the FERC data set used in this dissertation is broad enough to shed light on both *ex ante* and *ex post* behaviour of electric utilities affected by the Amendments.

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6 Christensen, L.R., F.M. Gollop, and R.E. Stevenson (1980), "Estimates of Capital Stocks and Capital Services Flows for Privately-Owned Electric Utilities in the United States, 1950-1975," University of Wisconsin-Madison, May.

7 See for example, Burtraw, D. (1999), "Cost Savings, Market Performance and Economic Benefits of the U.S. Acid Rain Program," in S. Sorrell and J. Skea ed., "Pollution for Sale: Emissions Trading and Joint Implementation," Edward Elgar. Cheltenham, United Kingdom, pp. 43-62; Schmalensee, R. P., L. Joskow, A. D. Ellerman, J. B. Montero and E. M. Bailey (1998), "An Interim Evaluation of Sulfur Dioxide Emissions," *Journal of Economic Perspectives*, 12(3), pp. 53-68; and Stavins, R.N. (2000), "Experience with Market-Based Environmental Policy Instruments," Discussion Paper 00-09, Resources for the Future, Washington, DC.

Table 3

SO_2 Emissions from Coal-Fuelled Electric Utilities: 1985 through 1995

		Total SO_2 Emissions (Millions of Tons)			
	GW Capacity	1990	1994	1995	% Change 1990 - 1995
Phase I Units	130.9	9.7	8.0	5.3	- 45%
Non-Phase I Units	333.2	5.9	6.3	6.6	+ 11%
Total	464.1	15.6	14.3	11.9	- 23%

Sources: "1995 Compliance Results, Acid Rain Program," U.S. EPA and EIA, *Form 767*.

7. Summary Statistics

Annual average values for the key variables used in the econometric and DEA models are presented in Table 4 below. [8] The values reported have been adjusted for inflation where appropriate, using the relevant price indices, namely the U.S. coal price index and the GDP deflator.

Table 4

Descriptive Statistics of the Sample

YEAR	VARIABLE	MEAN	ST. DEV.	MINIMUM	MAXIMUM
1985	Cost of Production ($ millions)	88.12	84.00	1.93	427.00
	Output (MW millions)	3.82	3.98	0.05	20.94
	Price of Coal ($ per ton)	39.03	8.98	22.55	65.51
	Price of Capital (user cost per $)	0.12	0	0.12	0.12
	Rate of Discount (real *r*)	0.11	0	0.11	0.11
	Capital Stock ($ millions)	187.24	204.94	8.16	926.00
	Quantity of Coal (tons)	1679.10	1719.80	16.00	8385.00
	Investment ($ millions)	4.37	5.99	0.01	29.27
1986	Cost of Production ($ millions)	84.35	79.94	2.09	422.00
	Output (MW millions)	3.78	4.05	0.04	21.17
	Price of Coal ($ per ton)	37.98	8.47	23.36	68.99
	Price of Capital (user cost per $)	0.09	0	0.09	0.09
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	196.36	209.94	8.34	931.00

[8] A concise summary of the data set concerning the pre- and post-regulation periods are presented in Chapters 3 and 4.

YEAR	VARIABLE	MEAN	ST. DEV.	MINIMUM	MAXIMUM
	Quantity of Coal (tons)	1620.00	1685.90	24.00	8033.00
	Investment ($ millions)	5.82	10.00	0.03	51.44
1987	Cost of Production ($ millions)	81.71	76.62	2.32	396.00
	Output (MW millions)	3.74	3.97	0.06	21.50
	Price of Coal ($ per ton)	36.65	7.16	23.23	55.40
	Price of Capital (user cost per $)	0.10	0	0.10	0.10
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	198.20	212.74	8.32	943.00
	Quantity of Coal (tons)	1652.10	1723.60	32.00	8253.00
	Investment ($ millions)	6.06	12.40	0.01	82.54
1988	Cost of Production ($ millions)	83.83	77.29	1.95	405.00
	Output (MW millions)	3.99	4.06	0.04	21.69
	Price of Coal ($ per ton)	35.61	6.72	22.98	51.08
	Price of Capital (user cost per $)	0.10	0	0.10	0.10
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	197.52	208.98	8.34	945.00
	Quantity of Coal (tons)	1727.70	1717.20	26.00	8455.00
	Investment ($ millions)	5.32	8.42	0.01	32.89
1989	Cost of Production ($ millions)	85.93	78.29	1.99	391.00
	Output (MW millions)	4.03	4.05	0.03	20.70
	Price of Coal ($ per ton)	34.95	7.72	19.87	53.60
	Price of Capital (user cost per $)	0.09	0	0.09	0.09
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	200.86	209.89	8.34	950.00
	Quantity of Coal (tons)	1720.90	1712.80	17.00	8019.00
	Investment ($ millions)	12.04	36.91	0	293.00
1990	Cost of Production ($ millions)	86.87	79.83	3.39	400.00
	Output (MW millions)	4.00	4.07	0.03	20.78
	Price of Coal ($ per ton)	35.28	7.81	14.16	50.40
	Price of Capital (user cost per $)	0.10	0	0.10	0.10
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	206.73	211.93	8.35	952.00
	Quantity of Coal (tons)	1725.20	1703.50	19.00	8135.00
	Investment ($ millions)	8.28	13.90	0	98.76
1991	Cost of Production ($ millions)	92.13	95.27	2.34	490.00
	Output (MW millions)	4.06	4.42	0.03	21.88
	Price of Coal ($ per ton)	35.08	7.89	13.95	49.42
	Price of Capital (user cost per $)	0.09	0	0.09	0.09
	Rate of Discount (real *r*)	0.09	0	0.09	0.09
	Capital Stock ($ millions)	212.27	214.58	8.47	961.00
	Quantity of Coal (tons)	1680.20	1798.70	10.00	8570.00
	Investment ($ millions)	6.11	7.00	0.06	35.72

YEAR	VARIABLE	MEAN	ST. DEV.	MINIMUM	MAXIMUM
1992	Cost of Production ($ millions)	85.82	79.93	1.88	367.00
	Output (MW millions)	3.95	4.21	0.03	20.90
	Price of Coal ($ per ton)	34.55	8.31	13.02	51.87
	Price of Capital (user cost per $)	0.08	0	0.08	0.08
	Rate of Discount (real *r*)	0.08	0	0.08	0.08
	Capital Stock ($ millions)	220.13	219.47	8.38	970.00
	Quantity of Coal (tons)	1713.20	1802.20	15.00	8142.00
	Investment ($ millions)	8.08	9.72	0.05	36.58
1993	Cost of Production ($ millions)	90.04	84.27	2.62	400.00
	Output (MW millions)	4.11	4.26	0.06	20.57
	Price of Coal ($ per ton)	34.19	8.01	13.71	47.82
	Price of Capital (user cost per $)	0.07	0	0.07	0.07
	Rate of Discount (real *r*)	0.07	0	0.07	0.07
	Capital Stock ($ millions)	228.15	227.98	8.36	1020.00
	Quantity of Coal (tons)	1701.10	1763.80	12.00	7958.00
	Investment ($ millions)	8.80	13.93	0.01	84.90
1994	Cost of Production ($ millions)	96.04	96.57	2.57	437.00
	Output (MW millions)	4.16	4.48	0.05	21.44
	Price of Coal ($ per ton)	33.95	8.38	13.56	57.69
	Price of Capital (user cost per $)	0.08	0	0.08	0.08
	Rate of Discount (real *r*)	0.08	0	0.08	0.08
	Capital Stock ($ millions)	237.48	230.14	8.37	994.00
	Quantity of Coal (tons)	1718.50	1809.40	28.00	8215.00
	Investment ($ millions)	12.32	16.71	0.01	75.73

8. FERC Form No. 1

In order to provide some guidance for the reader concerning the type of data that was used in this dissertation, excerpts from the FERC Form No. 1 (by courtesy of http://rimsweb2.ferc.fed.us and http://www.utility-info.com) are attached to this Appendix. FERC Form No. 1 is the Mandatory Annual Report submitted to the Federal Energy Regulatory Commission (FERC) by all leading electric utilities operating in the United States.

FERC FORM NO. I

ANNUAL REPORT OF MAJOR ELECTRIC UTILITIES

Name of Utility: NORTH AMERICAN POWER INC.				Dec. 31, XXXX
FERC Form 1 Page 110 & 111 COMPARATIVE BALANCE SHEET (ASSETS AND OTHER DEBITS)				
Line No.	Title of Account (a)	Ref. Page No. (b)	Balance at Beginning of Year (c)	Balance at End of Year (d)
1	**UTILITY PLANT**			
2	Utility Plant (101-106, 114)	200-201	xxxx	xxxx
3	Construction Work in Progress (107)	200-201	xxxx	xxxx
4	TOTAL Utility Plant (Enter Total of lines 2 and 3)		xxxx	xxxx
5	(Less) Accum. Prov. for Depr. Amort. Depl. (108, 111, 115)	200-201	xxxx	xxxx
6	Net Utility Plant (Enter Total of line 4 less 5)		xxxx	xxxx
7	Nuclear Fuel (120.1-120.4, 120.6)	202-203	xxxx	xxxx
8	(Less) Accum. Prov. for Amort. of Nucl. Fuel Assemblies (120.5)	202-203	xxxx	xxxx
9	Net Nuclear Fuel (Enter Total of line 7 less 8)		xxxx	xxxx
10	Net Utility Plant (Enter Total of lines 6 and 9)		xxxx	xxxx
11	Utility Plant Adjustments (116)	122	xxxx	xxxx
12	Gas Stored Underground-Noncurrent (117)		xxxx	xxxx
13	**OTHER PROPERTY AND INVESTMENTS**			
14	Nonutility Property (121)	221	xxxx	xxxx
15	(Less) Accum. Prov. for Depr. and Amort. (122)		xxxx	xxxx
16	Investments in Associated Companies (123)		xxxx	xxxx
17	Investment in Subsidiary Companies (123.1)	224-225	xxxx	xxxx
18	(For Cost of Account 123.1, See Footnote Page 224, line 42)			
19	Noncurrent Portion of Allowances	228-228	xxxx	xxxx
20	Other Investments (124)		xxxx	xxxx
21	Special Funds (125-128)		xxxx	xxxx
22	TOTAL Other Property and Investments (lines 14-17,19-21)		xxxx	xxxx
23	**CURRENT AND ACCRUED ASSETS**			
24	Cash (131)		xxxx	xxxx
26	Working Funds (135)		xxxx	xxxx
27	Temporary Cash Investments (136)		xxxx	xxxx
28	Notes Receivable (141)		xxxx	xxxx
29	Customer Accounts Receivable (142)		xxxx	xxxx
30	Other Accounts Receivable (143)		xxxx	xxxx
31	(Less) Accum. Prov. for Uncollectible Acct.-Credit (144)		xxxx	xxxx
32	Notes Receivable from Associated Companies (145)		xxxx	xxxx
33	Accounts Receivable from Assoc. Companies (146)		xxxx	xxxx
34	Fuel Stock (151)	227	xxxx	xxxx
35	Fuel Stock Expenses Undistributed (152)	227	xxxx	xxxx
36	Residuals (Elec) and Extracted Products	227	xxxx	xxxx
37	Plant Materials and Operating Supplies (154)	227	xxxx	xxxx
38	Merchandise (155)	227	xxxx	xxxx
39	Other Materials and Supplies (156)	227	xxxx	xxxx
40	Nuclear Materials Held for Sale (157)	227	xxxx	xxxx
41	Allowances (158.1 and 158.2)	228-228	xxxx	xxxx
42	(Less) Noncurrent Portion of Allowances	-	xxxx	xxxx
43	Stores Expense Undistributed (163)	227	xxxx	xxxx
44	Gas Stored Underground - Current (164.1)	-	xxxx	xxxx
45	Liquefied Natural Gas Stored/Held for Processing (164.2-164.3)	-	xxxx	xxxx
46	Prepayments (165)	-	xxxx	xxxx
47	Advances for Gas (166-167)	-	xxxx	xxxx
48	Interest and Dividends Receivable (171)	-	xxxx	xxxx
49	Rents Receivable (172)	-	xxxx	xxxx
50	Accrued Utility Revenues (173)	-	xxxx	xxxx
51	Miscellaneous Current and Accrued Assets (174)		xxxx	xxxx
52	TOTAL Current and Accrued Assets (total of lines 24 thru 51)		xxxx	xxxx
Page 110				
53	**DEFERRED DEBITS**			
54	Unamortized Debt Expenses (181)		xxxx	xxxx
55	Extraordinary Property Losses (182.1)	230	xxxx	xxxx
56	Unrecovered Plant and Regulatory Study Costs (182.2)	230	xxxx	xxxx
57	Other Regulatory Assets (182.3)	232	xxxx	xxxx
58	Prelim. Survey and Investigation Charges (Electric) (183)		xxxx	xxxx

60	Clearing Accounts (184)		xxxx	xxxx
61	Temporary Facilities (185)		xxxx	xxxx
62	Miscellaneous Deferred Debits (186)	233	xxxx	xxxx
63	Def. Losses from Disposition of Utility Plt. (187)		xxxx	xxxx
64	Research, Devel. and Demonstration Expend. (188)	352-353	xxxx	xxxx
65	Unamortized Loss on Reacquired Debt (189)		xxxx	xxxx
66	Accumulated Deferred Income Taxes (190)	234	xxxx	xxxx
67	Unrecovered Purchased Gas Costs (191)		xxxx	xxxx
68	TOTAL Deferred Debits (Enter Total of lines 54 thru 67)		xxxx	xxxx
69	TOTAL Assets and other Debits (Total of lines 10, 11, 12, 22, 52,		xxxx	xxxx

FERC Form 1 Page 112 & 113
COMPARATIVE BALANCE SHEET (LIABILITIES AND OTHER CREDITS)

Line No.	Title of Account (a)	Ref. Page No. (b)	Balance at Beginning of Year (c)	Balance at End of Year (d)
1	PROPRIETARY CAPITAL			
2	Common Stock Issued (201)	250-251	xxxx	xxxx
3	Preferred Stock Issued (204)	250-251	xxxx	xxxx
4	Capital Stock Subscribed (202, 205)	-	xxxx	xxxx
5	Stock Liability for Conversion (203, 206)	-	xxxx	xxxx
6	Premium on Capital Stock (207)	-	xxxx	xxxx
7	Other Paid-In Capital (208-211)	253	xxxx	xxxx
8	Installments Received on Capital Stock (212)	-	xxxx	xxxx
9	(Less) Discount on Capital Stock (213)	-	xxxx	xxxx
10	(Less) Capital Stock Expense (214)	-	xxxx	xxxx
11	Retained Earnings (215, 215.1, 216)	118-119	xxxx	xxxx
12	Unappropriated Undistributed Subsidiary Earnings (216.1)	118-119	xxxx	xxxx
13	(Less) Reacquired Capital Stock (217)	250-251	xxxx	xxxx
14	TOTAL Proprietary Capital (Total of lines 2 thru 13)	-	xxxx	xxxx
15	LONG-TERM DEBT			
16	Bonds (221)	256-257	xxxx	xxxx
17	(Less) Reacquired Bonds (222)	256-257	xxxx	xxxx
18	Advances from Associated Companies (223)	256-257	xxxx	xxxx
19	Other Long-Term Debt (224)	256-257	xxxx	xxxx
20	Unamortized Premium on Long-Term Debt (225)	-	xxxx	xxxx
21	(Less) Unamortized Discount on Long-Term Debt-Debit (226)	-	xxxx	xxxx
22	TOTAL Long-Term Debt (Total of lines 16 thru 21)	-	xxxx	xxxx
23	OTHER NONCURRENT LIABILITIES			
24	Obligations Under Capital Leases - Noncurrent (227)	-	xxxx	xxxx
25	Accumulated Provision for Property Insurance (228.1)	-	xxxx	xxxx
27	Accumulated Provision for Pensions and Benefits (228.3)	-	xxxx	xxxx
28	Accumulated Miscellaneous Operating Provisions (228.4)	-	xxxx	xxxx
29	Accumulated Provision for Rate Refunds (229)	-	xxxx	xxxx
30	TOTAL Other Noncurrent Liabilities (Total of lines 24 thru 29)	-	xxxx	xxxx
31	CURRENT AND ACCRUED LIABILITIES			
32	Notes Payable (231)	-	xxxx	xxxx
33	Accounts Payable (232)	-	xxxx	xxxx
34	Notes Payable to Associated Companies (233)	-	xxxx	xxxx
35	Accounts Payable to Associated Companies (234)	-	xxxx	xxxx
36	Customer Deposits (235)	-	xxxx	xxxx
37	Taxes Accrued (236)	262-263	xxxx	xxxx
38	Interest Accrued (237)	-	xxxx	xxxx
39	Dividends Declared (238)	-	xxxx	xxxx
40	Matured Long-Term Debt (239)	-	xxxx	xxxx
41	Matured Interest (240)	-	xxxx	xxxx
42	Tax Collections Payable (241)	-	xxxx	xxxx
43	Miscellaneous Current and Accrued Liabilities (242)	-	xxxx	xxxx
44	Obligations Under Capital Leases-Current (243)	-	xxxx	xxxx
45	TOTAL Current and Accrued Liabilities (Lines 32 thru 44)	-	xxxx	xxxx
46	DEFERRED CREDITS			
48	Accumulated Deferred Investment Tax Credits (255)	266-267	xxxx	xxxx
49	Deferred Gains from Disposition of Utility Plant (256)	-	xxxx	xxxx
50	Other Deferred Credits (253)	269	xxxx	xxxx
51	Other Regulatory Liabilities (254)	278	xxxx	xxxx
52	Unamortized Gain on Reacquired Debt (257)	-	xxxx	xxxx
54	TOTAL Deferred Credits (Total of lines 47 thru 53)	-	xxxx	xxxx

FERC Form 1 Pages 114 to 117
Income Statement

Line No.	Account (a)	Ref. P. No. (b)	TOTAL Cur. Year (c)	TOTAL Pre Year (d)	ELECTRIC UTILITY Cur. Year (e)	ELECTRIC UTILITY Pre Year (f)	GAS UTILITY Cur. Year (g)	GAS UTILITY Pre Year (h)	OTHER UTILITY Cur. Year (i)	OTHER UTILITY Pre Year (j)
1	**UTILITY OPERATING INCOME**									
2	Operating Revenues (400)	300-301	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
3	**Operating Expenses**									
4	Operation Expenses (401)	320-323	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
5	Maintenance Expenses (402)	320-323	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
6	Depreciation Expense (403)	336-338	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
7	Amort. & Depl. of Utility Plant (404-405)	336-338	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
8	Amort. of Utility Plant Acq. Adj. (406)	336-338	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
9	Amort. of Property Losses, Unrecovered Plant and		Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
	Regulatory Study Costs (407)									
10	Amort. of Conversion Expenses (407)	-	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
11	Regulatory Debits (407.3)	-	Xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
12	(Less) Regulatory Credits (407.4)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
13	Taxes Other Than Income Taxes (408.1)	262-263	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
14	Income Taxes - Federal (409.1)	262-263	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
15	- Other (409.1)	262-263	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
16	Provision for Deferred Inc. Taxes (410.1)	234, 272-277	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
17	(Less) Provision for Deferred Income Taxes - Cr.(411.1)	234, 272-277	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
18	Investment Tax Credit Adj. - Net (411.4)	266	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
19	(Less) Gains from Disp. of Utility Plant (411.6)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
20	Losses from Disp. of Utility Plant (411.7)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
21	(Less) Gains from Disposition of Allowances (411.8)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
22	Losses from Disposition of Allowances (411.9)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
23	TOTAL Utility Operating Expenses (Total of lines 4 thru 18)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
24	Net Utility Operating Income (Total of line 2 less 23)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
25	Net Utility Operating Income (Carried forward from page 114) (remainder omitted)	-	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

FERC Form 1 Pages 120 to 121
Statement Of Cash Flows

Line No.	Description (a)	Amount (b) $
1	Net Cash Flow from Operating Activities:	
2	Net Income (Line 72 on page 117)	xxxx
3	Noncash Charges (Credits) to Income:	
4	Depreciation and Depletion	xxxx
5	Amortization of (Specify): Peabody Buyout	xxxx
6	Unbilled Revenue	xxxx
8	Deferred Income Taxes (Net)	xxxx
9	Investment Tax Credit Adjustment (Net)	xxxx
10	Net (Increase) Decrease in Receivables	xxxx
11		

12	Net (Increase) Decrease in Allowances Inventory	xxxx
13	Net Increase (Decrease) in Payables and Accrued Expenses	xxxx
14	Net (Increase) Decrease in Other Regulatory Assets	xxxx
15	Net Increase (Decrease) in Other Regulatory Liabilities	xxxx
16	(Less) Allowance for Other Funds Used During Construction	xxxx
17	(Less) Undistributed Earnings from Subsidiary Companies	xxxx
18	Other: Other Current Assets	xxxx
19	Other Sources (Uses) Net	xxxx
20	Gain on Sale of Plant	xxxx
22	Net Cash Provided by (Used in) Operating Activities (Total of lines 2	xxxx
24	Cash Flows for Investment Activities:	
25	Construction and Acquisition of Plant (including land):	xxxx
26	Gross Additions to Utility Plant (less nuclear fuel)	xxxx
27	Gross Additions to Nuclear Fuel	xxxx
28	Gross Additions to Common Utility Plant	xxxx
29	Gross Additions to Nonutility Plant	xxxx
30	(Less) Allowance for Other Funds Used During Construction	xxxx
31	Other	xxxx
34	Cash Outflows for Plant (Total of lines 26 thru 33)	xxxx
36	Acquisition of Other Noncurrent Assets	xxxx
37	Proceeds from Disposal of Noncurrent Assets	xxxx
39	Investments in and Advances to Assoc. and Subsidiary Companies	xxxx
40	Contributions and Advances from Assoc. and Subsidiary Companies	xxxx
41	Disposition of Investments in (and Advances to)	
42	Associated and Subsidiary Companies	
44	Purchase of Investment Securities	xxxx
45	Proceeds from Sales of Investment Securities	xxxx
46	Loans Made or Purchased	xxxx
47	Collections on Loans	xxxx
49	Net (Increase) Decrease in Receivables	xxxx
50	Net (Increase) Decrease in Inventory	xxxx
51	Net (Increase) Decrease in	xxxx
52	Allowances Held for Speculation	xxxx
53	Net Increase (Decrease) in Payables and Accrued Expenses	xxxx
54		

56	Net Cash Provided by (Used in) Investing Activities	
57	(Total of lines 34 thru 55)	xxxx
59	Cash Flows from Financing Activities:	
60	Proceeds from Issuance of:	
61	Long-Term Debt	xxxx
62	Preferred Stock	xxxx
63	Common Stock	xxxx
64	Other:	xxxx
66	Net Increase in Short-Term Debt	xxxx
67	Other:	xxxx
70	Cash Provided by Outside Sources (Total of lines 61 thru 69)	xxxx
72	Payments for Retirement of:	
73	Long-term Debt	xxxx
74	Preferred Stock	xxxx
75	Common Stock	xxxx
76	Other:	xxxx
78	Net Decrease in Short-Term Debt	xxxx
80	Dividends on Preferred Stock	xxxx
81	Dividends on Common Stock	xxxx
82	Net Cash Provided by (Used in) Financing Activities	
83	(Total of lines 70 thru 81)	xxxx
85	Net Increase (Decrease) in Cash and Cash Equivalents	
86	(Total of lines 22, 57 and 83)	xxxx
88	Cash and Cash Equivalents at Beginning of Year	xxxx
90	Cash and Cash Equivalents at End of Year	xxxx

FERC Form 1 Pages 200 - 201
SUMMARY OF UTILITY PLANT AND ACCUMULATED PROVISIONS FOR DEPRECIATION, AMORTIZATION AND DEPLETION

Line No.	Item (a)	Total (b) $	Electric (c) $	Gas (d) $	Other (Specify) (e) $	Other (Specify) (f) $	Other (Specify) (g) $	Common (h) $
1	UTILITY PLANT							
3	Plant in Service (Classified)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
4	Property Under Capital Leases	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
5	Plant Purchased or Sold	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
6	Completed Construction not Classified	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
7	Experimental Plant Unclassified	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
8	TOTAL (Total of lines 3 thru 7)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
9	Leased to Others	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
10	Held for Future Use	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
11	Construction Work in Progress	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
12	Acquisition Adjustments	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
13	TOTAL Utility Plant (Total of lines 8 thru 12)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
14	Accum. Prov. for Depr., Amort., & Depl.	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
15	Net Utility Plant (Total of line 13 less 14)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
16	DETAIL OF ACCUMULATED PROVISIONS FOR							
17	In Service:							
18	Depreciation	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
19	Amort. and Depl. of Producing Nat. Gas Land and	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
20	Amort. of Underground Storage Land and Land	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
21	Amort. of Other Utility Plant	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
22	TOTAL In Service (Total of lines 18 thru 21)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
23	Leased to Others							
24	Depreciation	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
25	Amortization and Depletion	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
26	TOTAL Leased to Others (Total of lines 24 and 25)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
27	Held for Future Use							
28	Depreciation	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
29	Amortization	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
30	TOTAL Held for Future Use (Total of lines 28 and 29)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
31	Abandonment of Leases (Natural Gas)	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
32	Amortization of Plant Acquisition Adjustment	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx
33	TOTAL Accumulated Provisions	xxxx	xxxx	xxxx	XXXX	XXXX	xxxx	xxxx

FERC Form 1 Pages 204 - 207
Electric Plant in Service

Line No.	Account (a)	Balance at Beginning of Year (b)	Additions (c)	Retirements (d)	Adjustments (e)	Transfers (f)	Balance at End of Year (g)
1							
2	(301) Organization	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
3	(302) Franchises and Consents	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
4	(303) Miscellaneous Intangible Plant	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
5	TOTAL Intangible Plant (Total of lines 2, 3, and	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
6							
7	**A. Steam Production Plant**						
8	(310) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
9	(311) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
10	(312) Boiler Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
11	(313) Engines and Engine-Driven Generators	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
12	(314) Turbogenerator Units	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
13	(315) Accessory Electric Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
14	(316) Misc. Power Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
15	TOTAL Steam Production Plant (lines 8 - 14)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
16	**B. Nuclear Production Plant**						
17	(320) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
18	(321) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
19	(322) Reactor Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
20	(323) Turbogenerator Units	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
21	(324) Accessory Electric Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

22	(325) Misc. Power Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
23	TOTAL Nuclear Prod. Plant (lines 17 thru 22)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
24	**C. Hydraulic Production Plant**						
25	(330) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
26	(331) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
27	(332) Reservoirs, Dams, and Waterways	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
28	(333) Water Wheels, Turbines, and Generators	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
29	(334) Accessory Electric Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
30	(335) Misc. Power Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
31	(336) Roads, Railroads, and Bridges	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
32	TOTAL Hydraulic Production Plant (25 thru 31)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
33	**D. Other Production Plant**						
34	(340) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
35	(341) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
36	(342) Fuel Holders, Products, and Accessories	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
37	(343) Prime Movers	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
38	(344) Generators	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
39	(345) Accessory Electric Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
40	(346) Misc. Power Plant Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
41	TOTAL Other Production Plant (Total of lines 34	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
42	TOTAL Production Plant (5, 23, 32, and 41)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
43	**3. TRANSMISSION PLANT**						
44	(350) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
45	(352) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
46	(353) Station Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
47	(354) Towers and Fixtures	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
48	(355) Poles and Fixtures	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
49	(356) Overhead Conductors and Devices	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
50	(357) Underground Conduit	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
51	(358) Underground Conductors and Devices	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
52	(359) Roads and Trails	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
53	TOTAL Transmission Plant (lines 44 thru 52)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
54	**4. DISTRIBUTION PLANT**						
55	(360) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
56	(361) Structures and Improvements						
57	(362) Station Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
58	(363) Storage Battery Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
59	(364) Poles, Towers, and Fixtures	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
60	(365) Overhead Conductors and Devices	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
61	(366) Underground Conduit	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
62	(367) Underground Conductors and Devices	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
63	(368) Line Transformers	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
64	(369) Services	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
65	(370) Meters	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
66	(371) Installations on Customer Premises	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
67	(372) Leased Property on Customer Premises	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
68	(373) Street Lighting and Signal Systems	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
69	TOTAL Distribution Plant (lines 55 thru 68)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
70	**5. GENERAL PLANT**						
71	(389) Land and Land Rights	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
72	(390) Structures and Improvements	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
73	(391) Office Furniture and Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
74	(392) Transportation Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
75	(393) Stores Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
76	(394) Tools, Shop and Garage Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
77	(395) Laboratory Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
78	(396) Power Operated Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
79	(397) Communication Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
80	(398) Miscellaneous Equipment	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
81	SUBTOTAL (Enter Total of lines 71 thru 80)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
82	(399) Other Tangible Property	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
83	TOTAL General Plant (Total of lines 81 and 82)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
84	TOTAL (Accounts 101 and 106)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
85	(102) Electric Plant Purchased (See Instr. 8)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
86	(Less) (102) Electric Plant Sold (See Instr. 8)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
87	(103) Experimental Plant Unclassified	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
88	TOTAL Electric Plant in Service	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

FERC Form 1 Pages 300 & 301
Electric Operating Revenues

Line No.	Title of Account (a)	OPERATING REVENUES: Amount for Year (b)	OPERATING REVENUES: Amount for Previous Year (c)	MEGAWATT HOURS SOLD: Amount for Year (d)	MEGAWATT HOURS SOLD: Amount for Previous Year (e)	AVERAGE NUMBER OF CUSTOMERS PER MONTH: Number for Year (f)	AVERAGE NUMBER OF CUSTOMERS PER MONTH: Number for Previous Year (g)
1	**Sales of Electricity**						
2	(440) Residential Sales	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
3	**(442) Commercial and Industrial Sales**						
4	Small (or Commercial)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
5	Large (or Industrial)	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
6	(444) Public Highway Lighting	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
7	(445) Other Sales to Public Authorities	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
8	(446) Sales to Railroads and Railways	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
9	(448) Interdepartmental Sales	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
10	TOTAL Sales to Ultimate Consumers	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
11	(447) Sales for Resale	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
12	TOTAL Sales of Electricity	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
13	(Less) (449.1) Prov. for Rate Refunds	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
14	TOTAL Revenues of Prov. for Refunds	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
15	**Other Operating Revenues**						
16	(450) Forfeited Discounts	xxxx	xxxx				
17	(451) Miscellaneous Service Revenues	xxxx	xxxx				
18	(453) Sales of Water and Water Power	xxxx	xxxx				
19	(454) Rent from Electric Property	xxxx	xxxx				
20	(455) Interdepartmental Rents	xxxx	xxxx				
21	(456) Other Electric Revenues	xxxx	xxxx				
26	TOTAL Other Operating Revenues	xxxx	xxxx				
27	TOTAL Electric Operating Revenues	xxxx	xxxx				

FERC Form 1 Pages 320 - 323
Electric Operation and Maintenance Expenses

Line No.	Account (a)	Amount for Current Year (b)	Amount for Previous Year (c)
1	**POWER PRODUCTION EXPENSES**		
2	**A. Steam Power Generation**		
3	**Operation**		
4	(500) Operation Supervision and Engineering	xxxx	xxxx
5	(501) Fuel	xxxx	xxxx
6	(502) Steam Expenses	xxxx	xxxx
7	(503) Steam from Other Sources	xxxx	xxxx
8	(Less) (504) Steam Transferred-Cr.	xxxx	xxxx
9	(505) Electric Expenses	xxxx	xxxx
10	(506) Miscellaneous Steam Power Expenses	xxxx	xxxx
11	(507) Rents	xxxx	xxxx
12	(509) Allowances	xxxx	xxxx
13	TOTAL Operation (Total of lines 4 thru 12)	xxxx	xxxx
15	(510) Maintenance Supervision and Engineering	xxxx	xxxx
16	(511) Maintenance of Structures	xxxx	xxxx
17	(512) Maintenance of Boiler Plant	xxxx	xxxx
18	(513) Maintenance of Electric Plant	xxxx	xxxx
19	(514) Maintenance of Miscellaneous Steam Plant	xxxx	xxxx
20	TOTAL Maintenance(Total of lines 15 thru 19)	xxxx	xxxx
21	TOTAL Power Production Expenses-Steam Power	xxxx	xxxx
24	(517) Operation Supervision and Engineering	xxxx	xxxx
25	(518) Fuel	xxxx	xxxx
26	(519) Coolants and Water	xxxx	xxxx
27	(520) Steam Expenses	xxxx	xxxx
28	(521) Steam from Other Sources	xxxx	xxxx
29	(Less) (522) Steam Transferred-Cr.	xxxx	xxxx
30	(523) Electric Expenses	xxxx	xxxx
31	(524) Miscellaneous Nuclear Power Expenses	xxxx	xxxx
32	(525) Rents	xxxx	xxxx
33	TOTAL Operation (Total of lines 24 thru 32)	xxxx	xxxx

35	(528) Maintenance Supervision and Engineering	xxxx	xxxx
36	(529) Maintenance of Structures	xxxx	xxxx
37	(530) Maintenance of Reactor Plant Equipment	xxxx	xxxx
38	(531) Maintenance of Electric Plant	xxxx	xxxx
39	(532) Maintenance of Miscellaneous Nuclear Plant	xxxx	xxxx
40	TOTAL Maintenance (Enter Total of lines 35 thru 39)	xxxx	xxxx
41	TOTAL Power Production Expenses-Nuclear Power	xxxx	xxxx
43	**Operation**		
44	(535) Operation Supervision and Engineering	xxxx	xxxx
45	(536) Water for Power	xxxx	xxxx
46	(537) Hydraulic Expenses	xxxx	xxxx
47	(538) Electric Expenses	xxxx	xxxx
48	(539) Miscellaneous Hydraulic Power Generation Expenses	xxxx	xxxx
49	(540) Rents	xxxx	xxxx
50	TOTAL Operation (Total of lines 44 thru 49)	xxxx	xxxx
53	(541) Maintenance Supervision and Engineering	xxxx	xxxx
54	(542) Maintenance of Structures	xxxx	xxxx
55	(543) Maintenance of Reservoirs, Dams, and Waterways	xxxx	xxxx
56	(544) Maintenance of Electric Plant	xxxx	xxxx
57	(545) Maintenance of Miscellaneous Hydraulic Plant	xxxx	xxxx
58	TOTAL Maintenance (Total of lines 53 thru 57)	xxxx	xxxx
59	TOTAL Power Production Expenses-Hydraulic Power (lines 50	xxxx	xxxx
62	(546) Operation Supervision and Engineering	xxxx	xxxx
63	(547) Fuel	xxxx	xxxx
64	(548) Generation Expenses	xxxx	xxxx
65	(549) Miscellaneous Other Power Generation Expenses	xxxx	xxxx
66	(550) Rents	xxxx	xxxx
67	TOTAL Operation (Enter Total of lines 62 thru 66)	xxxx	xxxx
69	(551) Maintenance Supervision and Engineering	xxxx	xxxx
70	(552) Maintenance of Structures	xxxx	xxxx
71	(553) Maintenance of Generating and Electric Plant	xxxx	xxxx
72	(554) Maintenance of Miscellaneous Other Power Generation	xxxx	xxxx
73	TOTAL Maintenance (Total of lines 69 thru 72)	xxxx	xxxx
74	TOTAL Power Production Expenses-Other Power	xxxx	xxxx

77	(556) System Control and Load Dispatching	xxxx	xxxx
78	(557) Other Expenses	xxxx	xxxx
79	TOTAL Other Power Supply Expenses(Total of lines 76 thru	xxxx	xxxx
80	TOTAL Power Production Expenses	xxxx	xxxx
83	(560) Operation Supervision and Engineering	xxxx	xxxx
84	(561) Load Dispatching	xxxx	xxxx
85	(562) Station Expenses	xxxx	xxxx
86	(563) Overhead Line Expenses	xxxx	xxxx
87	(564) Underground Line Expenses	xxxx	xxxx
88	(565) Transmission of Electricity by Others	xxxx	xxxx
90	(567) Rents	xxxx	xxxx
91	TOTAL Operation (Total of lines 83 thru 90)	xxxx	xxxx
93	(568) Maintenance Supervision and Engineering	xxxx	xxxx
94	(569) Maintenance of Structures	xxxx	xxxx
95	(570) Maintenance of Station Equipment	xxxx	xxxx
96	(571) Maintenance of Overhead Lines	xxxx	xxxx
97	(572) Maintenance of Underground Lines	xxxx	xxxx
98	(573) Maintenance of Miscellaneous Transmission Plant	xxxx	xxxx
99	TOTAL Maintenance (Total of lines 93 thru 98)	xxxx	xxxx
100	TOTAL Transmission Expenses (Total of lines 91 and 99)	xxxx	xxxx
103	(580) Operation Supervision and Engineering	xxxx	xxxx
106	(582) Station Expenses	xxxx	xxxx
107	(583) Overhead Line Expenses	xxxx	xxxx
108	(584) Underground Line Expenses	xxxx	xxxx
109	(585) Street Lighting and Signal System Expenses	xxxx	xxxx
110	(586) Meter Expenses	xxxx	xxxx
111	(587) Customer Installations Expenses	xxxx	xxxx
112	(588) Miscellaneous Distribution Expenses	xxxx	xxxx
113	(589) Rents	xxxx	xxxx
114	TOTAL Operation (Total of lines 103 thru 113)	xxxx	xxxx
116	(590) Maintenance Supervision and Engineering	xxxx	xxxx
117	(591) Maintenance of Structures	xxxx	xxxx
302	Total Regular Full-Time Employees	xxxx	
303	Total Part-Time and Temporary Employees	xxxx	

FERC Form 1 Page 336
Depreciation And Amortization of Electric Plant
(Accounts 403, 404, 405)

Line No.	Functional Classification (a)	Depreciation Expense (Acc. 403) (b) $
1	Intangible Plant	XXXX
2	Steam Production Plant	XXXX
3	Nuclear Production Plant	XXXX
4	Hydraulic Production Plant-Conventional	XXXX
5	Hydraulic Production Plant-Pumped Storage	XXXX
6	Other Production Plant	XXXX
7	Transmission Plant	XXXX
8	Distribution Plant	XXXX
9	General Plant	XXXX
10	Common Plant-Electric	XXXX
11	TOTAL	XXXX

FERC Form 1 Page 401
Electric Energy Account

Line No.	Item (a)	MWh (b)
001	**SOURCES OF ENERGY**	
002	Generation (Excluding Station Use):	xxxx
003	Steam	xxxx
004	Nuclear	xxxx
005	Hydro-Conventional	xxxx
006	Hydro-Pumped Storage	xxxx
007	Other	xxxx
008	(Less) Energy for Pumping	xxxx
009	Net Generation (Total lines 3 thru 8)	xxxx
010	Purchases	xxxx
011	**Power Exchanges:**	
012	Received	xxxx
013	Delivered	xxxx
014	Net Exchanges(Line 12 minus 13)	xxxx
015	Transmission for Other (Wheeling)	
016	Wheeling: Received	xxxx
017	Wheeling: Delivered	xxxx
018	Net Transmission for Others (L 16 - L 17)	xxxx
019	Transmission by Others Losses	xxxx
020	TOTAL (lines 9, 10, 14, 18 & 19)	xxxx
022	Sales to Ultimate Consumers(Incl. Interdept. Sales)	xxxx
023	Requirements Sales for Resale	xxxx
024	Non-Requirements Sales for Resale	xxxx
025	Energy Furnished Without Charge	xxxx
026	Energy Used Company (Elec.Dept. only. Excl. Station Use)	xxxx
027	Total Energy Losses	xxxx
028	TOTAL (Total of Lines 22 thru 27)	xxxx

FERC Form 1 Page 430
Environmental Protection Facilities

Line No.	Classification of Cost (a)	CHANGES DURING YEAR			Bal. at End of Year (e) $	Actual Cost (f) $
		Additions (b) $	Retirements (c) $	Adjustments (d) $		
1	Air Pollution Control Facilities	xxxx	xxxx	xxxx	xxxx	xxxx
2	Water Pollution Control Facilities	xxxx	xxxx	xxxx	xxxx	xxxx
3	Solid Waste Disposal Costs	xxxx	xxxx	xxxx	xxxx	xxxx
4	Noise Abatement Equipment	xxxx	xxxx	xxxx	xxxx	xxxx
5	Esthetic Costs	xxxx	xxxx	xxxx	xxxx	xxxx
6	Additional Plant Capacity	xxxx	xxxx	xxxx	xxxx	xxxx
7	Miscellaneous	xxxx	xxxx	xxxx	xxxx	xxxx
8	TOTAL (Lines 1 thru 7)	xxxx	xxxx	xxxx	xxxx	xxxx
9	Construction Work in Progress	xxxx	xxxx	xxxx	xxxx	xxxx

APPENDIX II

Highlights of the Clean Air Act Amendments of 1990 (CAAA)

Allocation of Emissions Permits under the Clean Air Act Amendments of 1990

The primary goal of Title IV of the Clean Air Act Amendments of 1990 (hereafter the CAAA) is to reduce SO_2 emissions by 10 million tons below 1990 levels by 2000. To achieve these SO_2 reductions, the CAAA introduced a *two-phase* approach (namely Phase I & Phase II) involving the trading of annual SO_2 permits that gradually tightens the restrictions placed on fossil fuel-fired power plants. Phase I began in 1995 and affected 110 mostly coal-burning electric utility plants located in the eastern and mid-western states. Phase II, which started in January 2000, will further tighten the annual permissible SO_2 emissions.

PHASE I: Permits are being allocated by EPA for each year beginning in 1995 in a way that each unit's allocation is equivalent to an emission rate of *2.5 pounds of SO_2/mmBtu* (million British thermal units) of heat input, multiplied by the unit's baseline mmBtu (the average fossil fuel consumed from 1985 through 1987). These permit allocations are listed in Table A of the CAAA. Alternative or additional permit allocations are also made for various units, including affected units in Illinois, Indiana, and Ohio, which will be allocated a pro-rata share of 200,000 additional permits each year from 1995 to 1999. The total SO_2 (from all sources) and allocated Phase I permits by state are listed in Table 1.

TABLE 1

SO_2 EMISSION AND ESTIMATED PERMIT ALLOCATIONS BY STATE (PHASE I)

STATE	TOTAL SO2 EMISSIONS [1] (tons)	TOTAL SO_2 PERMITS	
		AMOUNT ALLOCATED (tons)	AS A % OF TOTAL EMISSIONS
Alabama	526,452	230,940	43.87
Florida	593,873	133,130	22.42
Georgia	989,946	581,600	58.75
Illinois	988,669	394,256	39.88
Indiana	1,423,835	717,063	50.36
Iowa	196,584	40,290	20.50
Kansas	131,838	4,220	3.20
Kentucky	796,652	278,250	34.93
Maryland	234,111	139,540	59.60
Michigan	427,799	42,340	9.90
Minnesota	117,298	4,270	3.64
Mississippi	104,375	54,610	52.32
Missouri	953,965	352,990	37.00
New Hampshire	72,581	32,190	44.35
New Jersey	92,301	20,780	22.51
New York	397,517	150,980	37.98
Ohio	2,243,991	960,200	42.79
Pennsylvania	1,154,185	534,140	46.28
Tennessee	806,882	386,430	47.89
West Virginia	942,784	497,870	52.81
Wisconsin	381,184	143,380	37.61
USA (Total)	**16,158,813**	**5,699,469**	**35.27**

Sources: *Clean Air Act Amendments of 1990, Table A, Rose et al (1992), and the author's computations.*

[1] Note that *total SO_2 emissions* represents the total emissions of *all* the utilities regulated by Phase II, which is broader than the 110 utilities included in Phase I of the program.

Table 1 shows that the state-wise allocations (see column 4 percentages) have been made differently despite the fact that individual allocations within each state have supposedly been made on the basis of the plants' emission levels during the 1985-1987 period. The prevalent market prices of permits during Phase I are shown in Table 2.

Table 2

SO_2 Program: Permits Prices 8/1994 – 3/2000

Month/Year	Avg. Price *	Month/Year	Avg. Price *
8/94	148	6/97	91
9/94	149	7/97	88
10/94	147	8/97	90
11/94	145	9/97	99
12/94	139	10/97	104
1/95	139	11/97	107
2/95	135	12/97	100
3/95	133	1/98	97
4/95	132	2/98	101
5/95	132	3/98	107
6/95	131	4/98	135
7/95	130	5/98	142
8/95	130	6/98	191
9/95	127	7/98	193
10/95	125	8/98	199
11/95	119	9/98	173
12/95	108	10/98	180
1/96	95	11/98	192
2/96	78	12/98	196
3/96	74	1/99	207
4/96	81	2/99	208
5/96	81	3/99	214
6/96	81	4/99	209
7/96	82	5/99	212
8/96	82	6/99	211
9/96	87	7/99	205
10/96	89	8/99	192
11/96	92	9/99	188
12/96	92	10/99	180
1/97	97	11/99	164
2/97	102	12/99	151
3/97	112	1/00	137
4/97	114	2/00	137
5/97	97	3/00	136

* 'Average Price' is the mean price of three prices published by three brokerage firms, namely Emissions Exchange, Cantor Fitzgerald EBS, Fieldston Publications (http://www.epa.gov).

PHASE II: Began in January, 2000. During Pahse II, the limits imposed on Phase I plants are tightened. In addition, emissions limits will also be imposed on smaller and relatively cleaner units. Permit allocation calculations are made for various types of units, such as coal- and gas-fired units with low and high emissions rates or low fuel consumption. In Phase II, EPA will allocate permits to each unit at an emission rate of *1.2 pounds of SO2/mmBtu* of heat input, multiplied by the unit's baseline. During Phase II, the CAAA place a cap at 8.95 million on the number of permits issued to units each year. This effectively caps emissions at 8.95

million tons annually and ensures that the mandated emissions reductions are maintained over time. [2] In addition, I was also able to collect utility-wise allocations of permits (planned) for *Phase II* from the U.S. department of Energy database and noticed that there will be a significant difference in the distribution mechanism for Phase II as compared to Phase I. The distribution of permits under Phase II was made according to the following formula:

1.2 pounds / mmBTU (based on mid-1980s fuel use unless specified otherwise)

To get a better picture of what has been occurring at the plant-level, I also collected data relating to plant-wise allocations of permits under Phase I, which are given in Table 3 below. These figures (except in the case of Illinois, Indiana, and Ohio where the pro rata share of 200,000 bonus permits have also been allocated) add up to the state-wise aggregate allocations shown in Table 1 above.

TABLE 3

PLANT-SPECIFIC ALLOCATIONS OF SO_2 PERMITS (PHASE I)

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
Alabama	Colbert	1	13,570
		2	15,310
		3	15,400
		4	15,410
		5	37,180
	E.C. Gaston	1	18,100
		2	18,540
		3	18,310
		4	19,280
		5	59,840
Florida	Big Ben	1	28,410
		2	27,100
		3	26,740
	Crist	6	19,200
		7	31,680
Georgia	Bowen	1	56,320
		2	54,770
		3	71,550
		4	71,740
	Hammond	1	8,780
		2	9,220
		3	8,910
		4	37,640
	J.M. McDonough	1	19,910
		2	20,600

[2] Visit http://www.epa.gov.

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
	Wansley	1	70,770
		2	65,430
	Yates	1	7,210
		2	7,040
		3	6,950
		4	8,910
		5	9,410
		6	24,760
		7	21,480
Illinois	Baldwin	1	42,010
		2	44,420
		3	42,550
	Coffeen	1	11,790
		2	35,670
	Grand Tower	4	5,910
	Henepin	2	18,410
	Joppa Steam	1	12,590
		2	10,770
		3	12,270
		4	11,360
		5	11,420
		6	10,620
	Kincaid	1	31,530
		2	33,810
	Meredosia	3	13,890
	Vermilion	2	8,880
Indiana	Bailly	7	11,180
	Breed	8	15,630
	Cayuga	1	18,500
		1	33,370
		2	34,130
	Clifty Creek	1	20,150
		2	19,810
		3	20,410
		4	20,080
		5	19,360
		6	20,380
	E.W. Stout	5	3,880
		6	4,770
		7	23,610
	F.B. Culley	2	4,290
		3	16,970

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
	F.E. Ratts	1	8,330
		2	8,480
	Gibson	1	40,400
		2	41,010
		3	41,080
		4	40,320
	H.T. Pritchard	6	5,770
	Michigan City	12	23,310
	Petersburg	1	16,430
		2	32,380
	R. Gallagher	1	6,490
		2	7,280
		3	6,530
		4	7,650
	Tanners Creek	4	24,820
	Wabash River	1	4,000
		2	2,860
		3	3,750
		5	3,670
		6	12,280
	Warrick	4	26,980
Iowa	Burlington	1	10,710
	Des Moines	7	2,320
	George Neal	1	1,290
	M.L. Kapp	2	13,800
	Prairie Creek	4	8,180
	Riverside	5	3,990
Kansas	Quindaro	2	4,220
Kentucky	Coleman	1	11,250
		2	12,840
		3	12,340
	Cooper	1	7,450
		2	15,320
	E.W. Brown	1	7,110
		2	10,910
		3	26,100
	Elmer Smith	1	6,520
		2	14,410
	Ghent	1	28,410
	Green River	4	7,820
	H.L. Spurlock	1	22,780
	Henderson II	1	13,340

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
		2	12,310
	Paradise	3	59,170
	Shawnee	10	10,170
Maryland	Chalk Point	1	21,910
		2	24,330
	C.P. Crane	1	10,330
		2	9,230
	Morgantown	1	35,260
		2	38,480
Michigan	J.H. Campbell	1	19,280
		2	23,060
Minnesota	High Bridge	6	4,270
Mississippi	Jack Watson	4	17,910
		5	36,700
Missouri	Asbury	1	16,190
	James River	5	4,850
	Labadie	1	40,110
		2	37,710
		3	40,310
		4	35,940
	Montrose	1	7,390
		2	8,200
		3	10,090
	New Madrid	1	28,240
		2	32,480
	Sibley	3	15,580
	Sioux	1	22,570
		2	23,690
	Thomas Hill	1	10,250
		2	19,390
New Hamp.	Merrimack	1	10,190
		2	22,000
New Jersey	B.L. England	1	9,060
		2	11,720
New York	Dunkirk	3	12,600
		4	14,060
	Greenbridge	4	7,540
	Milliken	1	11,170
		2	12,410
	Northport	1	19,810
		2	24,110
		3	26,480

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
	Port Jefferson	3	10,470
		4	12,330
Ohio	Ashtabula	5	16,740
	Avon Lake	8	11,650
		9	30,480
	Cardinal	1	34,270
		2	38,320
	Conesville	1	4,210
		2	4,890
		3	5,500
		4	48,770
	Eastlake	1	7,800
		2	8,640
		3	10,020
		4	14,510
		5	34,070
	Edgewater	4	5,050
	Gen. J.M. Gavin	1	79,080
		2	80,560
	Kyger Creek	1	19,280
		2	18,560
		3	17,910
		4	18,710
		5	18,740
	Miami Fort	5	760
		6	11,380
		7	38,510
	Muskingum River	1	14,880
		2	14,170
		3	13,950
		4	11,780
		5	40,470
	Niles	1	6,940
		2	9,100
	Pickway	5	4,30
	R.E. Burger	3	6,150
		4	10,780
		5	12,430
	W.H. Sammis	5	24,170
		6	39,930
		7	43,220
	W.C. Beckjord	5	8,950

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
		6	23,020
Pennsylvania	Armstrong	1	14,410
		2	15,430
	Brunner Island	1	27,760
		2	31,100
		3	53,820
	Cheswick	1	69,170
	Conemaugh	1	59,790
		2	66,450
	Hatfield's Ferry	1	37,830
		2	37,320
		3	40,270
	Martins Creek	1	12,660
		2	12,820
	Portland	1	5,940
		2	10,230
	Shawville	1	10,320
		2	10,320
		3	14,220
		4	14,070
	Sanbury	3	8,760
		4	11,450
Tennessee	Allen	1	15,320
		2	16,770
		3	15,670
	Cumberland	1	86,700
		2	94,840
	Gallatin	1	17,870
		2	17,310
		3	20,020
		4	21,260
	Johnsonville	1	7,790
		2	8,040
		3	8,410
		4	7,990
		5	8,240
		6	7,890
		7	8,980
		8	8,700
		9	7,080
		10	7,550
West Virginia	Albright	3	12,000

STATE	PLANT NAME	GENERATOR	PHASE I PERMITS
	Fort Martin	1	41,590
		2	41,200
	Harrison	1	48,620
		2	46,150
		3	41,500
	Kammer	1	18,740
		2	19,460
		3	17,390
	Mitchell	1	43,980
		2	45,510
	Mount Storm	1	43,720
		2	35,580
		3	42,430
Wisconsin	Edgewater	4	24,750
	La Crosse/Genoa	3	22,700
	Nelson Dewey	1	6,010
		2	5,220
	N. Oak Creek	1	5,140
		2	5,370
		3	6,320
		4	7,510
	Pulliam	8	9,670
	S. Oak Creek	5	12,040
		6	16,180
		7	15,790

U. S Clean Act Amendments of 1990
~ A Scientific Review ~

The original U. S. Clean Air Act was passed in 1963, but the national air pollution control program is actually based on the 1970 version of this act. The 1990 Clean Air Act Amendments revised the 1970 version further. The overall goal of the 1990 Amendments is to reduce air pollutants by 56 billion pounds a year - 224 pounds for every person in the country - by the time the provisions are fully implemented in 2005. The 1990 Amendments build on both the strengths of the Clean Air Act of 1970 and the country's environmental lessons learned over the past 20 years.

What Does the Clean Air Act Cover?

Two groups of air pollutants are regulated under the Clean Air Act.

There are six in the first group, which are called *criteria air* pollutants, namely ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, lead, and particulate matter (PM), which are found in relatively large quantities in the lower atmosphere, particularly in populated areas. They threaten human health and the environment across broad regions of the country. All of the *criteria* pollutants, except ozone, are directly discharged (or emitted) into the air from a wide variety of sources, such as industries, motor vehicles, and other human activities. Ozone is not directly discharged, but is formed in the presence of sunlight by a photochemical reaction between nitrogen dioxide, and volatile organic compounds (VOCs) which are fumes from oil-based paints and solvents. The Environmental Protection Agency (EPA) sets national standards for each of the criteria pollutants, based on health risk studies. All states must take action to ensure the standards are met. The EPA recently revised the standards for ozone and particulate matter, based on the findings of new health risk studies. Failure to meet the standards for criteria pollutants is called *non-attainment*. Many urban areas are classified as *non-attainment areas* for at least one of the criteria air pollutants. Areas which meet the standards are said to be *in attainment*.

The other group of pollutants - and there are hundreds in this group - are known as hazardous air pollutants (or "air toxics"). These pollutants are immediately hazardous to human health and are associated with specific sources. These air toxics cause a wide variety of health and environmental problems. The threat is higher for people living near large industrial facilities or in heavily polluted urban corridors. The list of toxics emitted into the air is a long one including *benzene* found in gasoline and *mercury* found in trace amounts in coal.

Requirements of the Clean Air Act

Areas of non-attainment for criteria pollutants have been classified according to the extent of pollution. The five classes range from marginal (relatively easy to clean up quickly) to extreme (needs a lot of work and a long time to clean up). The CAAA use these classes to tailor cleanup requirements to the severity of the pollution and set realistic deadlines for reaching cleanup goals. If deadlines are missed, the law allows more time to clean up, but usually a non-attainment area that has missed a cleanup deadline must meet the stricter requirements set for more polluted areas. Individual states do most of the planning for cleaning up criteria air pollutants, using a system of permits and inspections to ensure that power plants, factories, and other pollution sources meet their cleanup goals. A variety of cleanup methods are required in non-attainment areas, many of which involve motor vehicles. Cleaner fuels, cleaner new vehicles, better maintenance programs for vehicles on the road, and mass transportation may be required. Also, as pollution gets worse, more pollution controls are required for smaller sources of pollution.

The regulatory program for air toxics in the CAAA reflects an entirely new approach. The new law names 189 toxic air pollutants. Typically, they are carcinogens, mutagens (substances that can cause gene mutations), or reproductive toxins, and their sources are usually specific industries. The EPA designate major sources of these chemicals and then develop *maximum achievable control technology* (MACT) standards for each category over the next 10 years. These standards are based on the best control technologies that have been demonstrated in these industrial categories. State and local air pollution agencies bear the primary responsibility to ensure that industrial plants meet the standards. In setting the MACT standards, the EPA looks at only pollution control equipment and pollution prevention methods, such as substituting non-toxic chemicals for toxic ones currently in use. The 1990 law favours setting standards that industry must achieve, rather than dictating equipment that industry must install. This flexibility allows industry to develop its own cost-effective means of reducing air toxic emissions and yet still meet the goals of the act. The law includes unique incentives for industries to reduce their emissions early, rather than waiting for federal standards. Sources that reduce emissions by 90% or more before the MACT standards go into effect, have six additional years to comply with them. Other sections of the CAAA establish a program for the prevention of accidental release of air toxics from industrial plants through the Chemical Safety Board.

Enforcement

The CAAA established *enforcement* methods, which are used to make polluters obey the laws and regulations. Enforcement methods include citations, fines, and even jail terms for violators of the law. The intentional violation any of the requirements is now a felony offense. EPA and state and local governments are responsible for enforcement of the Clean Air Act, but if they do not enforce the law, members of the public can sue EPA or the states to initiate action. Citizens also can sue violators apart from any action taken by EPA or state or local governments. Before the CAAA, all enforcement actions had to be handled through the courts. Now, in some cases, EPA has the authority to fine violators without going to court first. The purpose of this new authority is to accelerate compliance with the law and to reduce court time and cost.

U.S. Coal Industry at a Glance

- It takes a little less than one pound of coal to produce one kilowatt-hour of electricity.
- Approximately 55% of U. S. electricity is generated from coal burning utilities. Approximate totals for other fuels: nuclear, 21%; hydroelectric, 10%; natural gas, 9%; and petroleum, 4%.
- Nearly 60% of the country's coal production comes from mines in Illinois and other states east of the Mississippi River.
- Coal represents more than 80% of known recoverable fossil fuel reserves in the U. S..
- The U.S. has 500 billion tons of coal accessible through current production methods. These deposits are sufficient to meet demand at current levels for at least 300 years.
- The 500 billion tons of U.S. coal have an energy value equal to about two trillion barrels of crude oil -- more than triple the world's known oil reserves.
- In energy content, *one* ton of bituminous coal equals approximately:
  - 24 million British thermal units (Btus)
  - 4 barrels of oil
  - 24,000 cubic feet of natural gas
  - 189 gallons of gasoline
- Coal is the lowest priced fossil fuel which is used for running utility company turbines. Coal's price decreased 40% in real terms from 1980 to 1990.
- Increases in coal-usage by U.S. electric utilities have saved the equivalent of nearly 3.2 million barrels of oil per day since 1973.
- The coal industry, with a value of approximately $23 billion, ranks among America's leading basic industries.
- Some 3,430 coal mines employ approximately 130,000 miners in the U.S.
- CAAA revised regulations to reduce sulfur dioxide emissions associated with the burning of fossil fuels. In order for coal-burning utilities to comply with the CAAA, they have a variety of options to select from, including allowances, technologies, closing plants or switching to low sulphur coal.

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Note: Statistical information is from the Illinois Department of Commerce and Community Affairs, the U. S. Department of Energy, the National Coal Association, and the National Energy Information Center.

APPENDIX III

Translog Function

Some Technical Aspects of the Translog Function

There are a number of technical aspects that one should consider in the empirical estimation of a translog cost function. In what follows, attempts will be made to address some of these aspects

Using Output (Q) as an Explanatory Variable:

In general, the cost function depicts a locus of points corresponding to a certain level of output (Q) for given input prices (p_i). However, in empirical studies, a question arises as to how Q should be treated, i.e., *exogenous* or *endogenous*. It has been the common practice in the literature to treat output as exogenous, including in the case of regulated electric utilities. The rationale is that the price of output is set by the regulator and that utilities have to sell whatever the quantity that is demanded at that price. This tradition had been formalized following a seminal paper by Engle, Hendry, & Richard (1983). They argued that as long as output (Q) satisfies the property of *weak exogeneity*, it also satisfies the properties of a regressor, and thus, it can be treated as exogenous in any econometric models.

In the case of electric utilities, however, optimal output (Q) is generated through the standard cost minimization problem corresponding to each period of time. Thus, data on electric power generation can be interpreted as a locus of optimal quantities produced during a certain period of time, thus by satisfying the so-called property of "*weak exogeneity*". In order to verify the empirical relevance of this property, we consulted several leading experts in the field, including those who are actively involved in environmental policy formulation in the United States.

As it is known, most of the public utilities are subject to a number of regulations simultaneously. Most common of all is the rate-of-return regulation which regulates the *price* that utilities could charge to their customers. Until the early 1970s (according to Dr. Burtraw at the *Resources for the Future*) each utility was liable, under traditional cost-based regulation, to serve customers living in a specific geographical area. This means that utilities had very little ability to change their output, and thus, it was considered exogenous. However, after the passage of the first set of Amendments to the U.S. Clean Air Act in both 1970 and 1990, this situation has somewhat changed. These two sets of Amendments were intended, among other things, to enhance competition among public utilities, and as a result, utilities were given some ability to adjust their production of electricity. However, the price was continued to be regulated by the government. Furthermore, discussions with Dr. Rose (the leading researcher at the National Regulatory Research Institute) revealed that the decision to produce how much electricity would also depend on the relevant state regulations.

In view of the changing regulatory framework in which electric utilities operate, some researchers have formed different opinions on how to treat utility output inn empirical analyses. Some scholars believe that it is more appropriate to treat output parametrically (technically speaking as exogenous), while others have adopted the practice of treating output endogenous. One of the complexities of treating output as endogenous is the problem of computationally difficult estimation of instrumental variables in non-linear frameworks.

Calculation of Shadow Prices using the Factor of Proportionality (k_i):

The need for "shadow prices" of inputs arises when firms subject to regulation, fail to minimize its actual production cost and hence, the marginal rates of technical substitution are no longer equal to the ratios of relevant market prices (Atkinson & Halvorsen, 1984).This means that the estimation of a neoclassical cost function using the actual input market prices is *not* appropriate. Atkinson & Halvorsen (1984) specified shadow prices as:

$$P_i^* = k_i P_i \qquad \text{A.III.1}$$

where P_i is the market price of input i and k_j is the *factor of proportionality.*

However, Atkinson & Halvorsen's formulation in (A.III.1) is general. Therefore, the exact functional form for the distortion factor (k_t) should be specified by the researcher on the basis of the particular circumstances. For the purpose of their study, Atkinson and Halvorsen (1998) define k_t as:

$$k_i = \exp\left(\delta_n + \delta_{ir}r + \sum_z \delta_{iz}\Delta z\right) \qquad \text{A.III.2}$$

where δ_n is the firm specific dummy, r is the discount rate (e.g. the real interest rate), and Δz are the rates of change of all inputs. In a series of recent papers, Kumbhakar (1992, 1993a, and 1993b) presents an alternative expression for k_j:

$$k_i = \left(1 + \beta_i + \beta_{iT}T + \beta_{iTT}T^2\right)^2 \qquad \text{A.II.3}$$

where β_n is the firm specific dummy, and T is an index of time.

However, Kumbhakar's formulation in (A.II.3) is likely to become problematic (primarily due to multi-collinearity) in econometric estimation if the index of time (T) is also an argument of the cost function, and if it has been interpreted as a proxy for measuring technological change. Since a particular attention is paid in this dissertation to technological change in electric utility industry, it was decided not to consider time as a factor driving a gap between *actual* and *shadow* prices of inputs. Since shadow prices of inputs are proportional to their market prices (because of differences between shadow and actual market prices of inputs which result from the gaps between "constrained" (i.e., regulated) and "unconstrained" (i.e., unregulated) equilibrium quantities of inputs), it seems appropriate that the factor of proportionality for each input (k_i) be specified as a function of variables that may cause its actual quantity to diverge from its unconstrained equilibrium quantity.

More often, inputs such as capital are considered to be *quasi-fixed*, i.e., they are affected by the discount rate (r), the rate that determines the flow of some inputs (such as investment) over time. Some authors refer to it as the "price of capital". With regulations in effect, the quantities of other variable inputs (such as coal) demanded by firms are further constrained. As a result, the divergence between regulated and unregulated quantities of *variable inputs* is affected by the induced rates of change in quasi-fixed inputs such as capital. Furthermore, it is often argued that the "input mix" of utilities is subject to change over time as a result of other external factors such as technical change. Thus, an index of time also seems essential in any dynamic specification of shadow prices to capture primarily the technological change over time.

In view of the above arguments, for the purpose of this study, shadow prices of all inputs were defined as functions of the rate of discount (r), the rates of change of all inputs (Δz), and an index of time (T):

$$k_{it} = \exp(\delta_{ir}r_t + \delta_{iz}\Delta z_{it} + \delta_{iT}T) \qquad \text{for } i = \text{coal, capital} \qquad \text{A.III.4}$$

TABLE 1

Estimation Results for the Alternative Specification of the Regulation Dummy: 1985-89: 0 and 1990-94: 1

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE	VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Constant	α_0	15.908 (13.910)	Plant 2	γ_2	0.77858 (3.0981)
Output	α_Q	-0.48647 (-2.5253)	Plant 3	γ_3	0.52584 (2.1280)
Price of Coal	α_1	0.21857 (4.2519)	Plant 4	γ_4	0.45581 (1.5320)
Rate of Discount	δ_r	0.78143 (3.7123)	Plant 5	γ_5	0.55355 (2.1971)
Annual Change in Coal Usage	δ_{z1}	-6.7340 (-2.7775)	Plant 6	γ_6	0.36062 (1.4606)
Time trend of Input Prices	δ_T	-0.00916 (-2.6745)	Plant 7	γ_7	0.54409 (1.8285)
Regulation Dummy	δ_{reg}	0.022018 (0.99978)	Plant 8	γ_8	0.31699 (1.2826)
Capacity Dummy	δ_{sz}	0.48440 (1.9565)	Plant 9	γ_9	0.50777 (2.0541)
Regional Dummy 1 (MW)	δ_{mw}	3.8506 (6.0147)	Plant 10	γ_{10}	0.12711 (0.57084)
Regional Dummy 2 (NE)	δ_{ne}	3.4918 (5.4710)	Plant 11	γ_{11}	0.11713 (0.53298)
Regional Dummy 3 (SE)	δ_{se}	3.5564 (5.4303)	Plant 12	γ_{12}	0.0014915 (0.007916)
Quadratic Output	β_{QQ}	0.078097 (5.6858)	Plant 13	γ_{13}	-0.070624 (-0.37606)
Quadratic Time Index	β_{TT}	0.007917 (4.7966)	Plant 14	γ_{14}	0.039429 (0.17856)
Cross-Price of Inputs	β_{11}	0.09417 (12.802)	Plant 15	γ_{15}	0.22224 (1.0100)
Cross-Price of Inputs	β_{12}	-0.007796 (-0.6161)	Plant 16	γ_{16}	0.33616 (1.7836)
Price of Coal and Output	β_{1Q}	0.02602 (6.6227)	Plant 17	γ_{17}	-0.60830 (-2.7427)
Price of Coal and Time	β_{1T}	0.011573 (3.7180)	Plant 18	γ_{18}	0.67523 (3.5975)
Price of Capital and Time	β_{2T}	-0.0078742 (-2.7800)	Plant 19	γ_{19}	0.10570 (0.47956)
Output and Time Index	β_{QT}	-0.0002937 (-0.17974)	Plant 20	γ_{20}	-0.050246 (-0.26778)
Index of Time	α_T	-0.033361 (-1.7903)	Plant 21	γ_{21}	-0.047749 (-0.21649)
Utility-Specific Dummy 1 (Plant 1)	γ_1	0.26785 (1.0815)	Plant 22	γ_{22}	-0.090872 (-0.40762)

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Plant 23	γ_{23}	0.17616 (0.94185)
Plant 24	γ_{24}	0.91651 (4.7863)
Plant 25	γ_{25}	0.28639 (1.5224)
Plant 26	γ_{26}	0.034509 (0.15697)
Plant 27	γ_{27}	-0.039485 (-0.17961)
Plant 28	γ_{28}	0.63985 (3.4201)
Plant 29	γ_{29}	0.40428 (2.1436)
Plant 30	γ_{30}	-0.21340 (-0.97198)
Plant 31	γ_{31}	0.56811 (3.0386)
Plant 32	γ_{32}	-0.40740 (-2.1542)
Plant 33	γ_{33}	-0.39407 (-2.0836)
Plant 34	γ_{34}	-0.57353 (-3.0498)
Plant 35	γ_{35}	-0.30815 (-1.6343)
Plant 36	γ_{36}	-0.047244 (-0.24996)
Plant 37	γ_{37}	-0.42657 (-1.4375)
Plant 38	γ_{38}	-0.016805 (-0.06804)
Plant 39	γ_{39}	0.59068 (1.9844)
Plant 40	γ_{40}	-1.1160 (-4.2455)
Plant 41	γ_{41}	0.74196 (2.5028)
Plant 42	γ_{42}	-0.28154 (-1.1347)
Plant 43	γ_{43}	-0.66957 (-2.6531)
Plant 44	γ_{44}	1.2412 (3.2875)
Plant 45	γ_{45}	0.89051 (2.3608)

VARIABLE NAME	PARAMETER	COEFFICIENT ESTIMATE
Plant 46	γ_{46}	0.30331 (0.85304)
Plant 47	γ_{47}	0.33662 (0.94658)
Plant 48	γ_{48}	0.011338 (0.06040)
Plant 49	γ_{49}	0.34999 (1.5577)
Plant 50	γ_{50}	0.39185 (2.1029)
Plant 51	γ_{51}	0.44540 (1.2519)
Plant 53	γ_{52}	0.28337 (0.79496)
Plant 54	γ_{53}	-0.10399 (-0.29191)
Plant 54	γ_{54}	0.30661 (0.81313)
Plant 55	γ_{55}	0.80368 (4.2647)
Plant 56	γ_{56}	0.065602 (0.34668)
Plant 57	γ_{57}	0.60427 (3.2256)
Plant 58	γ_{58}	0.75022 (3.9377)
Plant 59	γ_{59}	0.32488 (1.7331)
Plant 60	γ_{60}	0.067681 (0.35997)
Plant 61	γ_{61}	0.85660 (4.4871)
Plant 62	γ_{62}	0.46833 (2.5018)
Plant 63	γ_{63}	0.53305 (2.1612)
Plant 64	γ_{64}	0.17157 (0.69037)
Plant 65	γ_{65}	-0.54625 (-2.4763)
Plant 66	γ_{66}	-0.49740 (-2.2557)
Plant 67	γ_{67}	-0.71294 (-3.2173)
Plant 68	γ_{68}	-0.099992 (-0.45294)

* *t-values are in parentheses.*

APPENDIX IV

Efficiency Scores

Table 1

TE - Technical Efficiency, AE - Allocative Efficiency, EE - Economic Efficiency

	1985			1986			1987			1988			1989		
Firm	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE
1	0.852	0.819	0.697	0.818	0.884	0.724	0.715	0.897	0.642	0.888	0.886	0.787	0.878	0.868	0.762
2	0.786	0.814	0.639	0.738	0.897	0.662	0.666	0.890	0.593	0.920	0.793	0.729	0.823	0.866	0.712
3	0.720	0.891	0.641	0.694	0.960	0.666	0.652	0.897	0.585	0.822	0.866	0.713	0.778	0.871	0.678
4	0.806	0.795	0.641	0.787	0.860	0.677	0.687	0.884	0.607	0.895	0.832	0.745	0.795	0.866	0.688
5	0.885	0.802	0.710	0.863	0.881	0.761	0.750	0.892	0.669	0.951	0.837	0.796	0.890	0.867	0.771
6	0.822	0.816	0.671	0.788	0.887	0.699	0.566	0.894	0.506	0.911	0.846	0.770	0.841	0.868	0.730
7	0.798	0.800	0.638	0.790	0.886	0.699	0.688	0.891	0.613	0.856	0.842	0.721	0.832	0.869	0.723
8	0.836	0.792	0.662	0.778	0.874	0.679	0.694	0.890	0.618	0.884	0.834	0.737	0.815	0.865	0.705
9	0.743	0.835	0.621	0.709	0.899	0.637	0.661	0.895	0.592	0.789	0.882	0.696	0.856	0.877	0.751
10	0.780	0.790	0.616	0.719	0.874	0.628	0.619	0.894	0.553	0.790	0.839	0.663	0.733	0.873	0.641
11	0.659	0.839	0.553	0.622	0.901	0.560	0.549	0.907	0.497	0.693	0.883	0.612	0.676	0.875	0.592
12	0.601	0.981	0.589	0.668	0.913	0.610	0.611	0.940	0.575	0.681	0.958	0.652	0.686	0.895	0.614
13	0.839	0.774	0.649	0.741	0.864	0.640	0.634	0.893	0.566	0.797	0.845	0.673	0.745	0.874	0.651
14	0.807	0.795	0.642	0.730	0.889	0.649	0.615	0.900	0.553	0.810	0.859	0.696	0.757	0.869	0.658
15	0.623	0.829	0.516	0.562	0.930	0.522	0.509	0.916	0.466	0.668	0.866	0.579	0.616	0.880	0.542
16	0.604	1.000	0.604	0.634	0.999	0.634	0.616	0.932	0.574	0.703	0.954	0.671	0.702	0.900	0.632
17	0.559	0.991	0.554	0.570	0.993	0.566	0.509	0.982	0.500	0.656	0.994	0.652	0.588	0.948	0.557
18	0.602	0.925	0.556	0.726	0.926	0.673	0.697	0.899	0.627	0.879	0.838	0.736	0.775	0.873	0.677
19	0.610	0.995	0.607	0.650	0.990	0.644	0.579	0.999	0.579	0.685	0.998	0.684	0.716	0.911	0.652
20	0.809	0.706	0.571	0.777	0.753	0.585	0.684	0.768	0.525	0.790	0.792	0.626	0.857	0.797	0.683
21	0.712	0.909	0.647	0.709	0.945	0.670	0.670	0.914	0.613	0.766	0.901	0.690	0.796	0.890	0.709
22	0.580	0.996	0.578	0.546	0.991	0.541	0.534	1.000	0.533	0.611	0.956	0.585	0.642	0.904	0.580
23	0.734	0.788	0.578	0.660	0.916	0.605	0.597	0.904	0.540	0.768	0.826	0.634	0.702	0.873	0.613
24	0.902	0.683	0.616	0.888	0.709	0.630	0.816	0.685	0.559	0.887	0.766	0.679	0.889	0.735	0.654
25	0.544	0.996	0.542	0.564	0.994	0.561	0.517	0.972	0.502	0.604	0.998	0.603	0.626	0.922	0.577
26	0.598	0.998	0.597	0.582	0.998	0.581	0.566	0.945	0.535	0.718	0.981	0.705	0.822	0.901	0.741
27	0.799	0.762	0.608	1.000	0.852	0.852	0.661	0.832	0.550	0.841	0.799	0.672	0.766	0.855	0.655
28	0.856	0.725	0.621	0.712	0.854	0.608	0.658	0.835	0.550	0.820	0.802	0.657	1.000	0.867	0.867
29	0.745	0.762	0.567	0.651	0.860	0.560	0.604	0.875	0.529	0.769	0.801	0.616	0.760	0.807	0.614
30	0.808	0.906	0.733	0.738	0.939	0.692	0.670	0.918	0.615	0.839	0.884	0.742	0.806	0.871	0.702
31	0.692	0.805	0.558	0.575	0.957	0.550	0.558	0.906	0.506	0.709	0.852	0.604	0.973	0.881	0.857
32	0.789	0.727	0.573	0.679	0.854	0.579	0.622	0.837	0.521	0.799	0.797	0.637	0.718	0.866	0.622
33	0.616	0.941	0.580	0.620	0.921	0.571	0.555	0.915	0.507	0.695	0.902	0.626	0.587	0.890	0.523

	1985			1986			1987			1988			1989		
Firm	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE
34	0.715	0.837	0.598	0.675	0.902	0.609	0.603	0.898	0.542	0.573	0.808	0.463	0.583	0.967	0.564
35	0.731	0.729	0.533	0.761	0.802	0.610	0.664	0.817	0.543	0.547	0.797	0.436	0.734	0.868	0.637
36	0.453	0.962	0.436	0.416	0.992	0.413	0.448	0.984	0.440	0.579	0.996	0.577	0.558	0.997	0.557
37	0.895	0.773	0.692	0.730	0.852	0.622	0.617	0.888	0.549	0.839	0.813	0.682	0.755	0.872	0.658
38	0.635	0.995	0.631	0.612	0.995	0.609	0.603	0.953	0.575	0.698	0.998	0.697	0.757	0.917	0.695
39	1.000	0.650	0.650	1.000	0.671	0.671	1.000	0.609	0.609	1.000	0.743	0.743	0.798	0.872	0.695
40	0.562	0.974	0.547	0.590	0.966	0.570	0.540	0.982	0.531	0.637	0.981	0.625	0.604	0.999	0.604
41	0.502	0.896	0.450	0.526	0.926	0.487	0.469	0.954	0.447	0.075	0.994	0.074	0.564	0.915	0.516
42	0.529	0.928	0.491	0.517	0.949	0.491	0.256	0.967	0.247	0.614	0.977	0.600	0.051	0.971	0.049
43	0.538	0.849	0.457	0.547	0.863	0.472	0.472	0.901	0.425	0.153	0.966	0.148	0.534	0.896	0.478
44	0.869	0.800	0.695	0.828	0.872	0.722	0.741	0.887	0.658	0.958	0.835	0.800	0.869	0.864	0.752
45	1.000	1.000	1.000	0.973	1.000	0.973	1.000	0.882	0.882	1.000	0.784	0.784	0.988	0.871	0.860
46	0.758	0.999	0.757	0.809	0.985	0.796	0.758	0.920	0.697	0.855	0.933	0.798	0.916	0.883	0.809
47	0.766	0.997	0.764	0.932	0.995	0.927	1.000	1.000	1.000	1.000	1.000	1.000	0.712	0.874	0.622
48	0.674	0.833	0.561	0.632	0.917	0.580	0.556	0.902	0.501	0.665	0.856	0.570	0.589	0.885	0.521
49	0.866	0.737	0.638	0.779	0.831	0.647	0.684	0.852	0.583	0.873	0.806	0.704	0.788	0.867	0.683
50	0.788	0.708	0.558	0.872	0.715	0.623	0.790	0.688	0.544	0.786	0.760	0.598	0.854	0.693	0.592
51	0.893	0.983	0.878	0.978	0.981	0.960	0.936	0.990	0.927	1.000	0.996	0.996	1.000	1.000	1.000
52	0.394	0.992	0.391	0.498	0.990	0.493	0.989	0.980	0.969	0.729	0.997	0.726	0.426	0.916	0.391
53	0.619	0.982	0.608	0.625	0.968	0.605	0.549	0.975	0.535	0.811	0.894	0.725	0.668	0.998	0.667
54	0.749	0.936	0.701	0.977	1.000	0.976	0.734	0.905	0.664	0.898	0.889	0.799	0.882	0.875	0.772
55	0.853	0.713	0.608	0.760	0.811	0.616	0.628	0.883	0.555	0.868	0.782	0.678	0.825	0.793	0.654
56	0.577	0.997	0.575	0.587	0.995	0.584	0.500	0.979	0.489	0.607	0.999	0.606	0.650	0.924	0.601
57	0.954	0.668	0.637	0.952	0.689	0.656	0.607	0.649	0.393	0.920	0.756	0.696	1.000	0.672	0.672
58	0.986	0.695	0.685	0.977	0.735	0.718	0.868	0.729	0.633	0.993	0.778	0.772	0.964	0.769	0.742
59	0.990	0.696	0.689	0.956	0.727	0.695	0.804	0.704	0.566	0.963	0.770	0.741	0.958	0.739	0.708
60	0.636	0.976	0.621	0.658	0.961	0.632	0.632	0.917	0.579	0.754	0.914	0.688	0.756	0.888	0.671
61	0.761	0.789	0.601	0.695	0.878	0.610	0.614	0.894	0.549	0.745	0.839	0.625	0.707	0.874	0.618
62	1.000	0.684	0.684	0.975	0.711	0.694	0.911	0.685	0.623	0.993	0.764	0.758	1.000	0.730	0.730
63	0.965	1.000	0.964	1.000	1.000	1.000	0.707	0.922	0.652	0.839	0.931	0.780	0.835	0.877	0.733
64	0.898	0.983	0.883	0.803	0.986	0.792	0.594	0.997	0.592	0.720	0.997	0.718	0.727	0.943	0.686
65	0.645	0.985	0.635	0.669	0.979	0.655	0.639	0.918	0.587	0.762	0.934	0.712	0.749	0.883	0.661
66	0.578	0.979	0.566	0.518	1.000	0.518	0.616	0.947	0.584	0.696	0.961	0.669	0.675	0.898	0.606
67	0.594	0.995	0.592	0.585	0.995	0.582	0.545	0.981	0.534	0.634	0.999	0.634	0.688	0.910	0.627
68	0.598	0.996	0.595	0.697	0.997	0.695	0.513	0.949	0.487	0.623	0.998	0.622	0.636	0.899	0.572
mea	0.737	0.863	0.626	0.726	0.904	0.650	0.652	0.892	0.576	0.769	0.882	0.671	0.754	0.876	0.655

Table 1 (*contd...*)

TE - Technical Efficiency, AE - Allocative Efficiency, EE - Economic Efficiency

	1990			1991			1992			1993			1994		
Firm	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE
1	0.845	0.842	0.712	0.940	0.931	0.875	0.931	0.887	0.825	0.852	0.933	0.794	0.956	0.842	0.805
2	0.828	0.820	0.679	0.916	0.902	0.826	0.898	0.881	0.790	0.840	0.903	0.758	0.907	0.832	0.755
3	0.741	0.866	0.642	0.815	0.937	0.763	0.844	0.890	0.751	0.801	0.933	0.748	0.809	0.880	0.712
4	0.789	0.838	0.661	0.889	0.889	0.790	0.886	0.871	0.772	0.845	0.902	0.762	0.888	0.830	0.737
5	0.879	0.819	0.719	0.975	0.901	0.879	0.962	0.884	0.851	0.922	0.920	0.849	0.998	0.841	0.840
6	0.846	0.831	0.702	0.714	0.985	0.704	0.850	0.950	0.807	0.464	0.937	0.435	0.777	0.956	0.743
7	0.852	0.819	0.697	0.902	0.906	0.817	0.912	0.887	0.809	0.906	0.919	0.833	0.974	0.858	0.837
8	0.790	0.816	0.644	0.972	0.904	0.878	0.879	0.880	0.773	0.857	0.911	0.780	0.902	0.854	0.770
9	0.773	0.841	0.650	0.768	0.971	0.746	0.805	0.927	0.746	0.786	0.940	0.740	0.738	0.952	0.703
10	0.722	0.831	0.600	0.797	0.908	0.724	0.793	0.888	0.705	0.705	0.943	0.665	0.799	0.855	0.683
11	0.644	0.850	0.548	0.747	0.932	0.696	0.729	0.891	0.649	0.693	0.942	0.653	0.746	0.854	0.637
12	0.562	0.939	0.528	0.742	0.976	0.724	0.685	0.970	0.665	0.706	0.954	0.673	0.728	0.920	0.670
13	0.713	0.827	0.589	0.903	0.921	0.831	0.818	0.895	0.732	0.829	0.940	0.780	0.791	0.872	0.690
14	0.789	0.806	0.636	0.863	0.894	0.772	0.812	0.875	0.710	0.746	0.906	0.676	0.704	0.842	0.593
15	0.617	0.834	0.515	0.632	0.963	0.609	0.652	0.911	0.594	0.620	0.942	0.584	0.668	0.900	0.601
16	0.557	0.999	0.557	0.734	0.998	0.732	0.690	0.982	0.678	0.774	0.959	0.742	0.702	0.954	0.670
17	0.518	0.988	0.512	0.639	0.983	0.628	0.637	0.984	0.627	1.000	0.947	0.947	0.580	0.986	0.573
18	0.748	0.819	0.613	0.778	0.989	0.769	0.815	0.880	0.717	0.782	0.906	0.709	0.828	0.837	0.694
19	0.582	0.988	0.575	0.737	0.972	0.716	0.014	0.990	0.014	0.019	0.972	0.018	1.000	1.000	1.000
20	0.765	0.772	0.591	0.837	0.862	0.722	0.844	0.843	0.711	0.845	0.845	0.714	0.870	0.806	0.702
21	0.742	0.875	0.649	0.851	0.956	0.813	0.831	0.918	0.764	0.793	0.968	0.768	0.833	0.910	0.758
22	0.553	0.967	0.535	0.671	0.998	0.670	0.698	0.967	0.675	0.610	0.978	0.597	0.686	0.962	0.660
23	0.702	0.817	0.574	0.773	0.892	0.689	0.762	0.882	0.672	0.756	0.905	0.684	0.701	0.837	0.587
24	0.845	0.736	0.623	0.889	0.849	0.755	0.896	0.826	0.740	0.896	0.811	0.727	0.838	0.795	0.666
25	0.557	0.998	0.556	0.661	0.994	0.657	0.650	0.998	0.648	0.661	0.971	0.642	0.637	0.967	0.616
26	0.704	0.967	0.681	0.848	1.000	0.847	0.809	0.999	0.808	0.745	0.961	0.716	0.722	0.937	0.676
27	0.776	0.787	0.611	0.857	0.872	0.747	0.845	0.857	0.724	0.839	0.871	0.730	0.863	0.823	0.711
28	0.739	0.782	0.578	0.813	0.867	0.705	0.810	0.855	0.693	0.940	0.845	0.795	0.933	0.806	0.752
29	0.769	0.777	0.598	0.830	0.863	0.717	0.822	0.845	0.695	0.807	0.837	0.675	0.446	0.808	0.360
30	0.816	0.826	0.674	0.849	0.954	0.810	0.852	0.924	0.787	0.839	0.937	0.786	0.916	0.872	0.798
31	0.702	0.812	0.570	0.783	0.897	0.702	0.769	0.885	0.680	0.753	0.924	0.696	0.788	0.849	0.669
32	0.701	0.794	0.556	0.734	0.872	0.640	0.687	0.855	0.587	0.752	0.875	0.658	0.748	0.827	0.619
33	0.556	0.809	0.450	0.610	0.898	0.547	0.609	0.875	0.532	0.647	0.935	0.605	0.641	0.870	0.557
34	0.575	0.981	0.564	0.592	0.990	0.586	0.522	0.996	0.520	0.453	0.969	0.439	0.437	0.967	0.422

	1990			1991			1992			1993			1994		
Firm	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE	TE	AE	EE
35	0.701	0.794	0.556	0.702	0.876	0.615	0.616	0.870	0.535	0.679	0.875	0.594	0.783	0.822	0.643
36	0.483	0.989	0.478	0.618	0.990	0.612	0.632	0.989	0.625	0.614	0.980	0.601	0.685	0.969	0.664
37	0.796	0.793	0.631	0.762	0.881	0.672	0.812	0.877	0.712	0.816	0.894	0.730	0.857	0.838	0.719
38	0.630	0.999	0.630	0.798	0.995	0.795	0.760	0.996	0.757	0.786	0.974	0.765	0.773	0.964	0.745
39	1.000	0.674	0.674	1.000	0.817	0.817	1.000	0.777	0.777	0.901	0.891	0.803	1.000	0.787	0.787
40	0.569	0.964	0.549	0.678	0.955	0.647	0.668	0.962	0.643	0.668	0.988	0.660	0.624	0.995	0.621
41	0.515	0.912	0.469	0.609	0.836	0.509	0.621	0.891	0.554	0.604	0.997	0.602	0.590	0.965	0.570
42	0.532	0.955	0.508	0.158	0.877	0.139	0.336	0.762	0.256	0.671	0.990	0.664	0.613	0.980	0.600
43	0.526	0.866	0.455	0.628	0.766	0.481	0.628	0.812	0.511	0.574	0.909	0.522	0.587	0.878	0.515
44	0.782	0.878	0.687	0.954	0.924	0.882	1.000	0.876	0.876	0.969	0.870	0.843	0.999	0.825	0.825
45	0.983	0.887	0.873	0.994	0.956	0.950	0.973	0.919	0.894	0.938	0.854	0.801	0.928	0.931	0.864
46	0.834	0.910	0.759	1.000	1.000	1.000	0.996	0.962	0.958	1.000	0.950	0.950	1.000	0.948	0.948
47	1.000	1.000	1.000	0.623	0.949	0.591	1.000	1.000	1.000	0.891	0.955	0.851	0.923	0.954	0.881
48	0.527	0.952	0.501	0.619	0.912	0.565	0.577	0.887	0.512	0.575	0.942	0.542	0.624	0.861	0.537
49	0.801	0.789	0.632	0.827	0.878	0.726	0.756	0.860	0.650	0.731	0.887	0.649	0.758	0.825	0.625
50	0.823	0.728	0.600	0.896	0.850	0.762	0.889	0.831	0.739	0.835	0.809	0.675	0.745	0.805	0.599
51	0.781	0.985	0.770	0.942	0.982	0.925	0.838	0.986	0.826	0.876	0.974	0.853	0.888	0.995	0.884
52	1.000	0.976	0.976	0.341	0.994	0.339	0.273	0.998	0.273	1.000	1.000	1.000	0.721	0.995	0.717
53	0.647	0.977	0.633	0.786	0.970	0.763	0.763	0.982	0.750	0.834	0.986	0.822	0.641	0.957	0.613
54	0.865	0.849	0.735	0.980	0.933	0.914	0.641	0.911	0.584	0.544	0.896	0.488	0.992	0.905	0.898
55	0.794	0.776	0.616	0.870	0.872	0.758	0.882	0.846	0.746	0.885	0.835	0.739	0.904	0.802	0.725
56	0.549	0.998	0.548	0.670	0.991	0.664	0.669	0.994	0.665	0.660	0.985	0.651	0.747	0.993	0.741
57	0.945	0.709	0.671	0.953	0.833	0.794	0.972	0.803	0.780	1.000	0.783	0.783	0.969	0.785	0.761
58	1.000	0.767	0.767	0.967	0.857	0.829	0.982	0.837	0.822	0.989	0.834	0.825	0.987	0.797	0.786
59	0.865	0.766	0.662	0.951	0.856	0.814	0.939	0.832	0.782	0.945	0.820	0.775	0.934	0.793	0.740
60	0.702	0.896	0.629	0.783	0.966	0.756	0.805	0.930	0.748	0.771	0.961	0.741	0.766	0.917	0.702
61	0.743	0.810	0.602	0.835	0.912	0.762	0.799	0.884	0.707	0.750	0.926	0.695	0.804	0.854	0.687
62	0.936	0.744	0.696	1.000	0.852	0.852	1.000	0.831	0.831	1.000	0.813	0.813	0.999	0.796	0.795
63	0.814	0.853	0.694	0.831	0.999	0.831	0.897	0.912	0.818	0.878	0.927	0.814	0.947	0.846	0.802
64	0.645	0.996	0.642	0.815	0.981	0.800	0.783	0.994	0.778	0.801	0.964	0.772	0.770	0.976	0.751
65	0.677	0.903	0.611	0.749	0.998	0.748	0.809	0.933	0.755	0.700	0.950	0.665	0.742	0.909	0.675
66	0.611	0.957	0.585	0.725	0.999	0.724	0.725	0.946	0.686	0.961	0.973	0.935	0.836	0.969	0.810
67	0.534	0.998	0.533	0.641	0.995	0.638	0.637	0.996	0.634	0.590	0.975	0.576	0.637	0.966	0.615
68	0.581	0.969	0.563	0.682	0.999	0.682	0.719	0.960	0.690	0.596	0.969	0.578	0.624	0.926	0.578
mea	0.728	0.869	0.625	0.786	0.928	0.727	0.771	0.907	0.696	0.772	0.922	0.708	0.793	0.889	0.701

Table 2

CRSTE - CRS Technical Efficiency, VRSTE - VRS Technical Efficiency, SCALE - Scale Efficiency

	1985				1986				1987				1988			
#	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk
1	0.852	0.862	0.988	IRS	0.818	0.819	0.999	-	0.715	0.718	0.996	DRS	0.888	0.891	0.997	IRS
2	0.786	0.822	0.955	DRS	0.738	0.764	0.966	DRS	0.666	0.813	0.819	DRS	0.920	0.938	0.981	DRS
3	0.720	0.731	0.984	IRS	0.694	0.701	0.990	DRS	0.652	0.678	0.962	DRS	0.822	0.828	0.994	DRS
4	0.806	0.878	0.918	IRS	0.787	0.855	0.921	IRS	0.687	0.739	0.929	IRS	0.895	0.918	0.975	IRS
5	0.885	1.000	0.885	DRS	0.863	1.000	0.863	DRS	0.750	1.000	0.750	DRS	0.951	1.000	0.951	DRS
6	0.822	0.834	0.986	IRS	0.788	0.790	0.998	IRS	0.566	0.568	0.997	IRS	0.911	0.914	0.996	DRS
7	0.798	0.829	0.962	IRS	0.790	0.817	0.966	IRS	0.688	0.694	0.991	IRS	0.856	0.865	0.990	IRS
8	0.836	0.842	0.993	IRS	0.778	0.779	0.998	IRS	0.694	0.746	0.930	DRS	0.884	0.891	0.991	DRS
9	0.743	0.744	0.998	IRS	0.709	0.715	0.991	DRS	0.661	0.747	0.884	DRS	0.789	0.799	0.988	DRS
10	0.780	0.824	0.946	DRS	0.719	0.750	0.958	DRS	0.619	0.752	0.824	DRS	0.790	0.814	0.970	DRS
11	0.659	0.676	0.975	IRS	0.622	0.630	0.988	IRS	0.549	0.555	0.989	IRS	0.693	0.698	0.992	IRS
12	0.601	0.915	0.656	IRS	0.668	0.888	0.753	IRS	0.611	0.991	0.617	IRS	0.681	1.000	0.681	IRS
13	0.839	0.909	0.923	IRS	0.741	0.822	0.901	IRS	0.634	0.715	0.886	IRS	0.797	0.834	0.955	IRS
14	0.807	0.812	0.994	IRS	0.730	0.731	0.999	DRS	0.615	0.617	0.998	DRS	0.810	0.812	0.999	DRS
15	0.623	0.631	0.987	IRS	0.562	0.563	0.999	DRS	0.509	0.513	0.992	IRS	0.668	0.668	1.000	-
16	0.604	0.682	0.886	IRS	0.634	0.682	0.930	IRS	0.616	0.655	0.941	IRS	0.703	0.765	0.920	IRS
17	0.559	0.570	0.981	IRS	0.570	0.579	0.985	IRS	0.509	0.541	0.941	IRS	0.656	0.748	0.877	IRS
18	0.602	0.688	0.874	IRS	0.726	0.780	0.931	IRS	0.697	0.716	0.974	IRS	0.879	0.891	0.986	IRS
19	0.610	0.616	0.991	IRS	0.650	0.658	0.987	IRS	0.579	0.599	0.968	IRS	0.685	0.725	0.944	IRS
20	0.809	0.825	0.980	IRS	0.777	0.790	0.984	IRS	0.684	0.694	0.985	IRS	0.790	0.795	0.993	IRS
21	0.712	0.811	0.877	DRS	0.709	0.793	0.894	DRS	0.670	0.835	0.803	DRS	0.766	0.823	0.931	DRS
22	0.580	0.589	0.985	IRS	0.546	0.566	0.964	IRS	0.534	0.558	0.957	IRS	0.611	0.620	0.986	IRS
23	0.734	0.791	0.927	IRS	0.660	0.743	0.888	IRS	0.597	0.660	0.904	IRS	0.768	0.786	0.977	IRS
24	0.902	1.000	0.902	DRS	0.888	1.000	0.888	DRS	0.816	1.000	0.816	DRS	0.887	1.000	0.887	DRS
25	0.544	0.633	0.861	IRS	0.564	0.627	0.900	IRS	0.517	0.604	0.855	IRS	0.604	0.773	0.781	IRS
26	0.598	0.603	0.993	IRS	0.582	0.582	0.999	IRS	0.566	0.573	0.987	IRS	0.718	0.723	0.994	IRS
27	0.799	0.803	0.994	IRS	1.000	1.000	1.000	-	0.661	0.791	0.835	DRS	0.841	0.857	0.982	DRS
28	0.856	0.926	0.924	IRS	0.712	0.831	0.856	IRS	0.658	0.757	0.870	IRS	0.820	0.875	0.936	IRS
29	0.745	0.768	0.969	IRS	0.651	0.682	0.955	IRS	0.604	0.609	0.991	IRS	0.769	0.771	0.997	IRS
30	0.808	0.824	0.981	IRS	0.738	0.741	0.996	DRS	0.670	0.675	0.993	IRS	0.839	0.840	0.998	IRS
31	0.692	0.733	0.945	IRS	0.575	0.637	0.903	IRS	0.558	0.582	0.959	IRS	0.709	0.724	0.978	IRS
32	0.789	0.999	0.790	IRS	0.679	1.000	0.679	IRS	0.622	0.918	0.678	IRS	0.799	1.000	0.799	IRS
33	0.616	1.000	0.616	IRS	0.620	0.970	0.639	IRS	0.555	1.000	0.555	IRS	0.695	1.000	0.695	IRS

	1985				1986				1987				1988			
#	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk
34	0.715	0.918	0.778	IRS	0.675	0.893	0.756	IRS	0.603	0.838	0.720	IRS	0.573	0.757	0.757	IRS
35	0.731	1.000	0.731	IRS	0.761	1.000	0.761	IRS	0.664	1.000	0.664	IRS	0.547	1.000	0.547	IRS
36	0.453	0.551	0.823	IRS	0.416	0.527	0.790	IRS	0.448	0.593	0.755	IRS	0.579	0.801	0.723	IRS
37	0.895	0.945	0.948	IRS	0.730	0.785	0.930	IRS	0.617	0.664	0.930	IRS	0.839	0.852	0.985	IRS
38	0.635	0.637	0.997	IRS	0.612	0.620	0.988	DRS	0.603	0.627	0.962	DRS	0.698	0.699	0.999	DRS
39	1.000	1.000	1.000	-	1.000	1.000	1.000	-	1.000	1.000	1.000	-	1.000	1.000	1.000	-
40	0.562	0.574	0.979	IRS	0.590	0.606	0.974	IRS	0.540	0.544	0.993	IRS	0.637	0.704	0.905	IRS
41	0.502	1.000	0.502	IRS	0.526	1.000	0.526	IRS	0.469	1.000	0.469	IRS	0.075	1.000	0.075	IRS
42	0.529	0.634	0.834	IRS	0.517	0.626	0.827	IRS	0.256	0.402	0.636	IRS	0.614	1.000	0.614	IRS
43	0.538	0.735	0.732	IRS	0.547	0.770	0.711	IRS	0.472	0.702	0.671	IRS	0.153	0.848	0.180	IRS
44	0.869	1.000	0.869	IRS	0.828	0.949	0.872	IRS	0.741	0.856	0.866	IRS	0.958	1.000	0.958	IRS
45	1.000	1.000	1.000	-	0.973	1.000	0.973	DRS	1.000	1.000	1.000	-	1.000	1.000	1.000	-
46	0.758	0.773	0.981	DRS	0.809	0.892	0.907	DRS	0.758	0.874	0.867	DRS	0.855	0.916	0.934	DRS
47	0.766	0.772	0.992	IRS	0.932	0.934	0.998	IRS	1.000	1.000	1.000	-	1.000	1.000	1.000	-
48	0.674	0.776	0.868	IRS	0.632	0.751	0.842	IRS	0.556	0.656	0.847	IRS	0.665	0.722	0.922	IRS
49	0.866	0.905	0.957	DRS	0.779	0.816	0.954	DRS	0.684	0.888	0.771	DRS	0.873	0.897	0.974	DRS
50	0.788	0.853	0.924	IRS	0.872	0.899	0.970	IRS	0.790	0.837	0.943	IRS	0.786	0.810	0.971	IRS
51	0.893	0.901	0.992	IRS	0.978	0.981	0.997	IRS	0.936	0.951	0.984	DRS	1.000	1.000	1.000	-
52	0.394	0.410	0.961	IRS	0.498	0.520	0.958	IRS	0.989	1.000	0.989	IRS	0.729	0.896	0.813	IRS
53	0.619	0.631	0.981	IRS	0.625	0.652	0.959	IRS	0.549	0.554	0.989	IRS	0.811	0.908	0.894	IRS
54	0.749	0.820	0.913	IRS	0.977	1.000	0.977	IRS	0.734	0.755	0.972	IRS	0.898	0.919	0.977	IRS
55	0.853	0.877	0.973	IRS	0.760	0.798	0.953	IRS	0.628	0.675	0.930	IRS	0.868	0.873	0.994	IRS
56	0.577	0.724	0.797	IRS	0.587	0.722	0.813	IRS	0.500	0.660	0.757	IRS	0.607	0.869	0.699	IRS
57	0.954	1.000	0.954	DRS	0.952	1.000	0.952	DRS	0.607	0.628	0.966	DRS	0.920	1.000	0.920	DRS
58	0.986	0.993	0.993	IRS	0.977	0.978	0.999	DRS	0.868	0.912	0.952	DRS	0.993	0.997	0.997	DRS
59	0.990	0.999	0.990	IRS	0.956	0.958	0.998	DRS	0.804	0.831	0.967	DRS	0.963	0.966	0.997	DRS
60	0.636	0.750	0.849	IRS	0.658	0.741	0.888	IRS	0.632	0.674	0.938	IRS	0.754	0.819	0.920	IRS
61	0.761	0.805	0.946	IRS	0.695	0.744	0.934	IRS	0.614	0.640	0.960	IRS	0.745	0.762	0.978	IRS
62	1.000	1.000	1.000	-	0.975	1.000	0.975	DRS	0.911	1.000	0.911	DRS	0.993	1.000	0.993	DRS
63	0.965	1.000	0.965	IRS	1.000	1.000	1.000	-	0.707	0.732	0.966	IRS	0.839	0.867	0.968	IRS
64	0.898	0.934	0.962	IRS	0.803	0.842	0.954	IRS	0.594	0.666	0.891	IRS	0.720	0.906	0.794	IRS
65	0.645	0.694	0.930	IRS	0.669	0.686	0.976	IRS	0.639	0.655	0.976	IRS	0.762	0.783	0.974	IRS
66	0.578	0.628	0.920	IRS	0.518	0.551	0.940	IRS	0.616	0.647	0.953	IRS	0.696	0.734	0.949	IRS
67	0.594	0.607	0.980	IRS	0.585	0.599	0.977	IRS	0.545	0.594	0.917	IRS	0.634	0.727	0.873	IRS
68	0.598	0.611	0.978	IRS	0.697	0.705	0.989	IRS	0.513	0.547	0.938	IRS	0.623	0.683	0.911	IRS
MEAN	0.737	0.803	0.921	–	0.726	0.792	0.922	–	0.652	0.738	0.892	–	0.769	0.857	0.902	–

Table 2 (*contd...*)

CRSTE - CRS Technical Efficiency, VRSTE - VRS Technical Efficiency, SCALE - Scale Efficiency

#	1989				1990				1991				1992			
	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk
1	0.878	0.886	0.991	DRS	0.845	0.849	0.995	IRS	0.940	0.947	0.993	IRS	0.931	0.946	0.985	DRS
2	0.823	0.885	0.929	DRS	0.828	0.887	0.934	DRS	0.916	0.921	0.994	DRS	0.898	0.922	0.974	DRS
3	0.778	0.785	0.991	DRS	0.741	0.744	0.996	IRS	0.815	0.820	0.994	IRS	0.844	0.858	0.984	DRS
4	0.795	0.803	0.991	IRS	0.789	0.836	0.944	IRS	0.889	0.906	0.980	IRS	0.886	0.891	0.995	DRS
5	0.890	1.000	0.890	DRS	0.879	1.000	0.879	DRS	0.975	1.000	0.975	DRS	0.962	1.000	0.962	DRS
6	0.841	0.853	0.986	DRS	0.846	0.848	0.997	IRS	0.714	0.734	0.974	IRS	0.850	0.850	1.000	-
7	0.832	0.835	0.996	DRS	0.852	0.864	0.986	IRS	0.902	0.913	0.988	IRS	0.912	0.921	0.990	DRS
8	0.815	0.852	0.957	DRS	0.790	0.791	0.999	IRS	0.972	0.975	0.997	IRS	0.879	0.895	0.982	DRS
9	0.856	0.865	0.990	DRS	0.773	0.781	0.989	DRS	0.768	0.774	0.993	IRS	0.805	0.809	0.995	DRS
10	0.733	0.777	0.944	DRS	0.722	0.759	0.951	DRS	0.797	0.797	1.000	-	0.793	0.811	0.979	DRS
11	0.676	0.681	0.993	DRS	0.644	0.652	0.987	IRS	0.747	0.755	0.990	IRS	0.729	0.738	0.988	DRS
12	0.686	0.791	0.867	IRS	0.562	0.745	0.755	IRS	0.742	0.882	0.842	IRS	0.685	0.889	0.771	IRS
13	0.745	0.756	0.985	IRS	0.713	0.761	0.937	IRS	0.903	0.935	0.965	IRS	0.818	0.836	0.979	IRS
14	0.757	0.793	0.954	DRS	0.789	0.793	0.995	DRS	0.863	0.865	0.998	IRS	0.812	0.827	0.982	DRS
15	0.616	0.621	0.993	DRS	0.617	0.619	0.997	IRS	0.632	0.640	0.988	IRS	0.652	0.655	0.994	DRS
16	0.702	0.723	0.971	IRS	0.557	0.614	0.908	IRS	0.734	0.769	0.954	IRS	0.690	0.732	0.943	IRS
17	0.588	0.612	0.960	IRS	0.518	0.533	0.972	IRS	0.639	0.649	0.986	IRS	0.637	0.650	0.979	IRS
18	0.775	0.777	0.998	DRS	0.748	0.768	0.973	IRS	0.778	0.829	0.939	IRS	0.815	0.824	0.990	DRS
19	0.716	0.720	0.994	IRS	0.582	0.591	0.985	IRS	0.737	0.752	0.981	IRS	0.014	0.130	0.111	IRS
20	0.857	0.879	0.975	DRS	0.765	0.771	0.992	IRS	0.837	0.842	0.995	IRS	0.844	0.845	0.999	DRS
21	0.796	0.853	0.933	DRS	0.742	0.835	0.888	DRS	0.851	0.860	0.990	DRS	0.831	0.850	0.978	DRS
22	0.642	0.644	0.997	IRS	0.553	0.567	0.976	IRS	0.671	0.679	0.988	IRS	0.698	0.700	0.998	IRS
23	0.702	0.705	0.996	IRS	0.702	0.732	0.959	IRS	0.773	0.788	0.980	IRS	0.762	0.764	0.997	DRS
24	0.889	1.000	0.889	DRS	0.845	1.000	0.845	DRS	0.889	1.000	0.889	DRS	0.896	1.000	0.896	DRS
25	0.626	0.668	0.936	IRS	0.557	0.626	0.890	IRS	0.661	0.702	0.941	IRS	0.650	0.710	0.915	IRS
26	0.822	0.825	0.997	DRS	0.704	0.709	0.992	IRS	0.848	0.856	0.991	IRS	0.809	0.811	0.997	IRS
27	0.766	0.838	0.914	DRS	0.776	0.792	0.981	DRS	0.857	0.857	1.000	-	0.845	0.854	0.990	DRS
28	1.000	1.000	1.000	-	0.739	0.793	0.932	IRS	0.813	0.853	0.953	IRS	0.810	0.859	0.942	IRS
29	0.760	0.799	0.952	DRS	0.769	0.772	0.996	IRS	0.830	0.833	0.997	IRS	0.822	0.826	0.995	DRS
30	0.806	0.813	0.991	DRS	0.816	0.817	0.999	IRS	0.849	0.858	0.990	IRS	0.852	0.854	0.998	DRS
31	0.973	0.976	0.997	DRS	0.702	0.717	0.978	IRS	0.783	0.793	0.987	IRS	0.769	0.775	0.992	DRS
32	0.718	0.936	0.767	IRS	0.701	0.931	0.752	IRS	0.734	0.941	0.779	IRS	0.687	0.909	0.756	IRS
33	0.587	0.732	0.802	IRS	0.556	0.707	0.786	IRS	0.610	0.770	0.792	IRS	0.609	0.760	0.800	IRS

#	1989				1990				1991				1992			
	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk
34	0.583	1.000	0.583	IRS	0.575	1.000	0.575	IRS	0.592	1.000	0.592	IRS	0.522	1.000	0.522	IRS
35	0.734	1.000	0.734	IRS	0.701	1.000	0.701	IRS	0.702	1.000	0.702	IRS	0.616	1.000	0.616	IRS
36	0.558	0.667	0.837	IRS	0.483	0.541	0.894	IRS	0.618	0.661	0.935	IRS	0.632	0.686	0.921	IRS
37	0.755	0.755	0.999	DRS	0.796	0.814	0.978	IRS	0.762	0.774	0.984	IRS	0.812	0.817	0.994	DRS
38	0.757	0.761	0.994	DRS	0.630	0.643	0.980	DRS	0.798	0.800	0.998	IRS	0.760	0.764	0.995	DRS
39	0.798	0.850	0.939	DRS	1.000	1.000	1.000	-	1.000	1.000	1.000	-	1.000	1.000	1.000	-
40	0.604	0.620	0.973	IRS	0.569	0.569	1.000	-	0.678	0.688	0.985	IRS	0.668	0.680	0.982	IRS
41	0.564	1.000	0.564	IRS	0.515	1.000	0.515	IRS	0.609	1.000	0.609	IRS	0.621	1.000	0.621	IRS
42	0.051	0.290	0.174	IRS	0.532	0.608	0.876	IRS	0.158	0.348	0.455	IRS	0.336	1.000	0.336	IRS
43	0.534	0.653	0.817	IRS	0.526	0.696	0.756	IRS	0.628	0.777	0.807	IRS	0.628	0.804	0.782	IRS
44	0.869	0.884	0.984	IRS	0.782	0.816	0.959	IRS	0.954	1.000	0.954	IRS	1.000	1.000	1.000	-
45	0.988	1.000	0.988	DRS	0.983	1.000	0.983	DRS	0.994	0.997	0.996	IRS	0.973	0.982	0.991	DRS
46	0.916	0.945	0.969	DRS	0.834	0.927	0.900	DRS	1.000	1.000	1.000	-	0.996	1.000	0.996	DRS
47	0.712	0.717	0.993	DRS	1.000	1.000	1.000	-	0.623	0.630	0.988	IRS	1.000	1.000	1.000	-
48	0.589	0.601	0.980	IRS	0.527	0.559	0.943	IRS	0.619	0.657	0.942	IRS	0.577	0.605	0.954	IRS
49	0.788	0.891	0.885	DRS	0.801	0.844	0.949	DRS	0.827	0.830	0.997	DRS	0.756	0.767	0.985	DRS
50	0.854	1.000	0.854	IRS	0.823	0.863	0.954	IRS	0.896	0.930	0.963	IRS	0.889	0.940	0.945	IRS
51	1.000	1.000	1.000	-	0.781	0.782	1.000	-	0.942	0.947	0.995	IRS	0.838	0.841	0.996	IRS
52	0.426	0.446	0.956	IRS	1.000	1.000	1.000	-	0.341	0.357	0.954	IRS	0.273	0.305	0.896	IRS
53	0.668	0.676	0.988	IRS	0.647	0.647	1.000	-	0.786	0.796	0.988	IRS	0.763	0.770	0.992	IRS
54	0.882	0.884	0.998	IRS	0.865	0.890	0.973	IRS	0.980	0.998	0.982	IRS	0.641	0.654	0.980	IRS
55	0.825	0.839	0.984	DRS	0.794	0.805	0.987	IRS	0.870	0.879	0.990	IRS	0.882	0.883	0.999	DRS
56	0.650	0.719	0.904	IRS	0.549	0.641	0.856	IRS	0.670	0.746	0.899	IRS	0.669	0.763	0.877	IRS
57	1.000	1.000	1.000	-	0.945	1.000	0.945	DRS	0.953	1.000	0.953	DRS	0.972	1.000	0.972	DRS
58	0.964	0.981	0.983	DRS	1.000	1.000	1.000	-	0.967	0.970	0.998	IRS	0.982	0.983	0.999	DRS
59	0.958	0.961	0.997	DRS	0.865	0.869	0.995	IRS	0.951	0.954	0.997	IRS	0.939	0.941	0.999	IRS
60	0.756	0.767	0.985	IRS	0.702	0.753	0.932	IRS	0.783	0.825	0.949	IRS	0.805	0.831	0.969	IRS
61	0.707	0.708	0.998	DRS	0.743	0.762	0.975	IRS	0.835	0.852	0.980	IRS	0.799	0.805	0.993	DRS
62	1.000	1.000	1.000	-	0.936	0.968	0.967	DRS	1.000	1.000	1.000	-	1.000	1.000	1.000	-
63	0.835	0.837	0.998	IRS	0.814	0.831	0.980	IRS	0.831	0.864	0.962	IRS	0.897	0.898	0.999	DRS
64	0.727	0.772	0.942	IRS	0.645	0.671	0.961	IRS	0.815	0.837	0.974	IRS	0.783	0.799	0.980	IRS
65	0.749	0.751	0.997	IRS	0.677	0.699	0.969	IRS	0.749	0.769	0.974	IRS	0.809	0.811	0.998	IRS
66	0.675	0.684	0.986	IRS	0.611	0.642	0.953	IRS	0.725	0.752	0.963	IRS	0.725	0.735	0.987	IRS
67	0.688	0.704	0.977	IRS	0.534	0.557	0.959	IRS	0.641	0.652	0.984	IRS	0.637	0.668	0.953	IRS
68	0.636	0.649	0.980	IRS	0.581	0.611	0.950	IRS	0.682	0.708	0.963	IRS	0.719	0.732	0.982	IRS
MEAN	0.754	0.804	0.933	–	0.728	0.782	0.934	–	0.786	0.831	0.944	–	0.771	0.826	0.927	–

Table 2 (*contd...*)

CRSTE - CRS Technical Efficiency, VRSTE - VRS Technical Efficiency, SCALE - Scale Efficiency

	1993				1994					1993				1994			
#	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk	#	CRSTE	VRSTE	SCALE	Rmk	CRSTE	VRSTE	SCALE	Rmk
1	0.852	0.858	0.993	IRS	0.956	0.956	1.000	-	35	0.679	1.000	0.679	IRS	0.783	1.000	0.783	IRS
2	0.840	0.872	0.963	DRS	0.907	0.908	0.999	DRS	36	0.614	0.683	0.899	IRS	0.685	0.745	0.920	IRS
3	0.801	0.804	0.997	IRS	0.809	0.809	1.000	-	37	0.816	0.832	0.980	IRS	0.857	0.857	1.000	-
4	0.845	0.887	0.952	IRS	0.888	0.888	0.999	-	38	0.786	0.786	1.000	-	0.773	0.774	0.999	IRS
5	0.922	1.000	0.922	DRS	0.998	1.000	0.998	DRS	39	0.901	0.924	0.974	DRS	1.000	1.000	1.000	-
6	0.464	0.479	0.969	IRS	0.777	0.796	0.976	IRS	40	0.668	0.671	0.996	DRS	0.624	0.625	0.998	IRS
7	0.906	0.925	0.979	IRS	0.974	0.975	1.000	-	41	0.604	1.000	0.604	IRS	0.590	1.000	0.590	IRS
8	0.857	0.859	0.997	IRS	0.902	0.902	1.000	-	42	0.671	0.745	0.901	IRS	0.613	0.709	0.863	IRS
9	0.786	0.791	0.994	IRS	0.738	0.746	0.989	IRS	43	0.574	0.813	0.707	IRS	0.587	0.838	0.700	IRS
10	0.705	0.722	0.977	DRS	0.799	0.799	1.000	-	44	0.969	1.000	0.969	IRS	0.999	1.000	0.999	IRS
11	0.693	0.699	0.991	IRS	0.746	0.746	1.000	-	45	0.938	0.943	0.995	IRS	0.928	0.928	1.000	-
12	0.706	0.942	0.750	IRS	0.728	0.922	0.790	IRS	46	1.000	1.000	1.000	-	1.000	1.000	1.000	-
13	0.829	0.907	0.914	IRS	0.791	0.839	0.943	IRS	47	0.891	0.899	0.991	IRS	0.923	0.931	0.991	IRS
14	0.746	0.747	0.999	IRS	0.704	0.704	1.000	-	48	0.575	0.625	0.920	IRS	0.624	0.643	0.970	IRS
15	0.620	0.625	0.992	IRS	0.668	0.668	1.000	-	49	0.731	0.738	0.990	DRS	0.758	0.758	1.000	-
16	0.774	0.805	0.961	IRS	0.702	0.747	0.940	IRS	50	0.835	0.889	0.939	IRS	0.745	0.767	0.972	IRS
17	1.000	1.000	1.000	-	0.580	0.611	0.950	IRS	51	0.876	0.894	0.979	DRS	0.888	0.920	0.966	DRS
18	0.782	0.797	0.981	IRS	0.828	0.829	1.000	-	52	1.000	1.000	1.000	-	0.721	0.739	0.975	IRS
19	0.019	0.146	0.128	IRS	1.000	1.000	1.000	-	53	0.834	0.851	0.980	DRS	0.641	0.644	0.994	IRS
20	0.845	0.852	0.991	IRS	0.870	0.870	1.000	-	54	0.544	0.568	0.959	IRS	0.992	1.000	0.992	IRS
21	0.793	0.825	0.961	DRS	0.833	0.834	0.999	DRS	55	0.885	0.893	0.990	IRS	0.904	0.904	1.000	-
22	0.610	0.621	0.982	IRS	0.686	0.700	0.980	IRS	56	0.660	0.825	0.800	IRS	0.747	0.919	0.813	IRS
23	0.756	0.783	0.966	IRS	0.701	0.702	0.999	-	57	1.000	1.000	1.000	-	0.969	1.000	0.969	DRS
24	0.896	1.000	0.896	DRS	0.838	1.000	0.838	DRS	58	0.989	0.993	0.996	IRS	0.987	0.987	1.000	-
25	0.661	0.704	0.940	IRS	0.637	0.700	0.910	IRS	59	0.945	0.950	0.995	IRS	0.934	0.934	1.000	-
26	0.745	0.753	0.989	IRS	0.722	0.726	0.994	IRS	60	0.771	0.815	0.946	IRS	0.766	0.807	0.949	IRS
27	0.839	0.842	0.995	DRS	0.863	0.863	1.000	-	61	0.750	0.775	0.968	IRS	0.804	0.805	1.000	-
28	0.940	0.982	0.957	IRS	0.933	0.940	0.992	IRS	62	1.000	1.000	1.000	-	0.999	1.000	0.999	DRS
29	0.807	0.810	0.996	IRS	0.446	0.446	1.000	-	63	0.878	0.899	0.977	IRS	0.947	0.948	1.000	-
30	0.839	0.842	0.996	IRS	0.916	0.916	1.000	-	64	0.801	0.835	0.959	IRS	0.770	0.819	0.940	IRS
31	0.753	0.770	0.977	IRS	0.788	0.788	1.000	-	65	0.700	0.715	0.980	IRS	0.742	0.747	0.994	IRS
32	0.752	0.972	0.774	IRS	0.748	0.895	0.836	IRS	66	0.961	0.981	0.979	IRS	0.836	0.862	0.970	IRS
33	0.647	0.819	0.789	IRS	0.641	0.750	0.854	IRS	67	0.590	0.615	0.961	IRS	0.637	0.668	0.954	IRS
34	0.453	1.000	0.453	IRS	0.437	1.000	0.437	IRS	68	0.596	0.614	0.970	IRS	0.624	0.636	0.982	IRS
AVG	0.772	0.827	0.928	–	0.793	0.837	0.951	–	AVG	0.772	0.827	0.928	–	0.793	0.837	0.951	–

Table 3

EFFICIENCY SCORES
Averages Across States

Technical Efficiency

	AB	FL	GE	IL	IN	IO	KT	MD	MS	NJ	NY	OH	TN	WS
1985	0.852	0.771	0.817	0.684	0.714	0.661	0.666	0.848	0.776	0.644	0.684	0.845	0.932	0.604
1986	0.818	0.740	0.786	0.656	0.698	0.630	0.646	0.886	0.761	0.738	0.801	0.820	0.902	0.617
1987	0.715	0.668	0.672	0.583	0.629	0.578	0.565	0.875	0.677	0.963	0.642	0.696	0.651	0.578
1988	0.888	0.879	0.878	0.725	0.763	0.639	0.574	0.953	0.775	0.865	0.855	0.855	0.780	0.679
1989	0.878	0.799	0.847	0.688	0.795	0.636	0.580	0.871	0.744	0.713	0.775	0.858	0.781	0.687
1990	0.845	0.786	0.828	0.640	0.714	0.603	0.653	0.900	0.717	0.891	0.756	0.817	0.730	0.601
1991	0.940	0.873	0.866	0.757	0.798	0.651	0.662	0.893	0.781	0.642	0.883	0.879	0.823	0.699
1992	0.931	0.876	0.882	0.727	0.744	0.613	0.689	0.992	0.741	0.556	0.702	0.881	0.840	0.723
1993	0.852	0.829	0.787	0.759	0.735	0.629	0.717	0.950	0.714	0.938	0.689	0.875	0.840	0.712
1994	0.956	0.868	0.878	0.715	0.790	0.659	0.721	0.963	0.709	0.805	0.817	0.889	0.859	0.710

Allocative Efficiency

	AB	FL	GE	IL	IN	IO	KT	MD	MS	NJ	NY	OH	TN	WS
1985	0.819	0.833	0.809	0.875	0.854	0.839	0.866	0.949	0.759	0.988	0.959	0.777	0.992	0.989
1986	0.884	0.906	0.885	0.920	0.906	0.894	0.889	0.963	0.821	0.986	0.984	0.813	0.993	0.993
1987	0.897	0.890	0.892	0.921	0.889	0.890	0.893	0.922	0.814	0.985	0.940	0.805	0.960	0.949
1988	0.886	0.830	0.848	0.900	0.871	0.860	0.925	0.888	0.807	0.997	0.892	0.825	0.964	0.973
1989	0.868	0.868	0.869	0.889	0.863	0.918	0.920	0.873	0.815	0.958	0.937	0.799	0.910	0.898
1990	0.842	0.841	0.825	0.884	0.852	0.873	0.880	0.919	0.823	0.981	0.913	0.808	0.925	0.957
1991	0.931	0.909	0.933	0.947	0.926	0.925	0.875	0.957	0.880	0.988	0.952	0.892	0.990	0.998
1992	0.887	0.881	0.906	0.925	0.905	0.917	0.868	0.939	0.859	0.992	0.947	0.870	0.953	0.959
1993	0.933	0.913	0.925	0.942	0.909	0.927	0.949	0.907	0.879	0.987	0.941	0.870	0.946	0.967
1994	0.842	0.847	0.892	0.898	0.872	0.891	0.915	0.914	0.830	0.995	0.931	0.842	0.911	0.943

Economic Efficiency

	AB	FL	GE	IL	IN	IO	KT	MD	MS	NJ	NY	OH	TN	WS
1985	0.697	0.640	0.660	0.590	0.599	0.544	0.560	0.804	0.586	0.635	0.655	0.638	0.924	0.597
1986	0.724	0.668	0.695	0.601	0.625	0.556	0.560	0.855	0.617	0.727	0.791	0.651	0.896	0.613
1987	0.642	0.595	0.600	0.536	0.555	0.511	0.483	0.809	0.543	0.948	0.600	0.548	0.622	0.548
1988	0.787	0.729	0.744	0.650	0.659	0.548	0.510	0.846	0.624	0.861	0.762	0.696	0.749	0.659
1989	0.762	0.693	0.736	0.611	0.684	0.581	0.528	0.761	0.599	0.696	0.720	0.675	0.710	0.617
1990	0.712	0.661	0.682	0.561	0.602	0.521	0.559	0.830	0.578	0.873	0.684	0.649	0.668	0.573
1991	0.875	0.793	0.805	0.715	0.737	0.600	0.580	0.856	0.684	0.632	0.839	0.779	0.816	0.698
1992	0.825	0.771	0.797	0.670	0.666	0.560	0.601	0.932	0.634	0.550	0.667	0.760	0.798	0.691
1993	0.794	0.756	0.727	0.715	0.661	0.579	0.678	0.861	0.622	0.927	0.655	0.753	0.793	0.689
1994	0.805	0.735	0.779	0.640	0.689	0.581	0.651	0.880	0.587	0.801	0.756	0.742	0.777	0.670

Table 4

EFFICIENCY SCORES
Averages Across Regions

	TE			AE			EE		
	North East	South East	Mid West	North East	South East	Mid West	North East	South East	Mid West
1985	0.725	0.807	0.714	0.965	0.864	0.849	0.698	0.696	0.592
1986	0.808	0.778	0.697	0.978	0.911	0.891	0.791	0.709	0.610
1987	0.826	0.654	0.623	0.949	0.907	0.878	0.786	0.588	0.540
1988	0.891	0.800	0.739	0.925	0.891	0.873	0.823	0.704	0.639
1989	0.786	0.777	0.735	0.923	0.887	0.864	0.725	0.686	0.628
1990	0.849	0.768	0.682	0.937	0.863	0.866	0.796	0.656	0.580
1991	0.806	0.833	0.761	0.966	0.928	0.928	0.775	0.774	0.702
1992	0.750	0.844	0.738	0.959	0.899	0.906	0.716	0.759	0.664
1993	0.859	0.805	0.737	0.945	0.933	0.916	0.814	0.750	0.670
1994	0.861	0.856	0.745	0.947	0.882	0.879	0.812	0.749	0.651

Table 5

AVERAGE EFFICIENCY SCORES ACROSS PERIODS
1985/89 vs. 1990/94

	Tech. Efficiency (TE)		Alloc. Efficiency (AE)		Econo. Efficiency (EE)	
	1985/89	**1990/94**	**1985/89**	**1990/94**	**1985/89**	**1990/94**
AB	0.830	0.905	0.871	0.887	0.722	0.802
FL	0.771	0.846	0.865	0.878	0.665	0.743
GE	0.800	0.848	0.861	0.896	0.687	0.758
IL	0.667	0.720	0.901	0.919	0.598	0.660
IN	0.720	0.756	0.877	0.893	0.624	0.671
IO	0.629	0.631	0.880	0.907	0.548	0.568
KT	0.606	0.688	0.899	0.898	0.528	0.614
ML	0.887	0.939	0.919	0.927	0.815	0.872
MS	0.746	0.732	0.803	0.854	0.594	0.621
NJ	0.784	0.766	0.983	0.989	0.773	0.756
NY	0.751	0.769	0.942	0.937	0.705	0.720
OH	0.815	0.868	0.804	0.856	0.641	0.737
TN	0.809	0.818	0.964	0.945	0.780	0.770
WS	0.633	0.689	0.960	0.965	0.607	0.664
US AVG	**0.746**	**0.784**	**0.895**	**0.911**	**0.663**	**0.711**

Table 6

RETURNS TO SCALE FOR 68 ELECTRIC UTILITIES

State	Constant Returns to Scale		Increasing Returns to Scale		Decreasing Returns to Scale	
	1989	1994	1989	1994	1989	1994
Alabama (01)	-	01	-	-	01	-
Florida (03)	-	02	01	-	02	01
Georgia (05)	-	02	-	02	05	01
Illinois (08)	-	03	04	04	04	01
Indiana (14)	01	05	04	07	09	02
Iowa (05)	-	-	05	05	-	-
Kentucky (07)	-	01	04	05	03	01
Maryland (04)	-	02	01	02	03	-
Missouri (03)	-	-	02	02	01	01
New Jersey (02)	01	01	01	01	-	-
New York (02)	-	-	02	02	-	-
Ohio (08)	02	02	02	04	04	02
Tennessee (02)	-	01	02	01	-	-
Wisconsin (04)	-	-	04	04	-	-
TOTAL (68)	**04** (6%)	**20** (29%)	**32** (47%)	**39** (58%)	**32** (47%)	**09** (13%)

Table 7

HAUSMAN TEST: *Random Effects vs Fixed Effects*

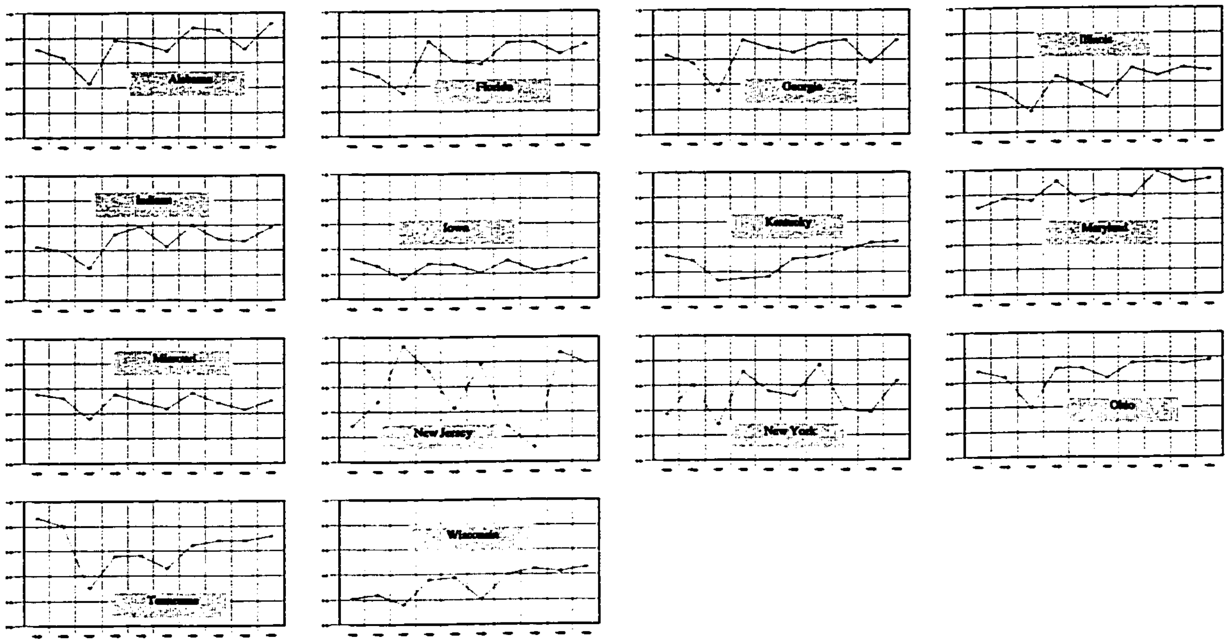
Dependent Variable	Calculated Hausman Statistic	Reject (H_0) (Yes/No)
TE	42.59	No
AE	5.17	No
EE	12.29	No

Notes:
1. H_0: *The random model is appropriate.*
2. The *Hasuman Statistic* is distributed as a *chi-square* with one degree of freedom.
3. At 5% level, critical value is 3.841.

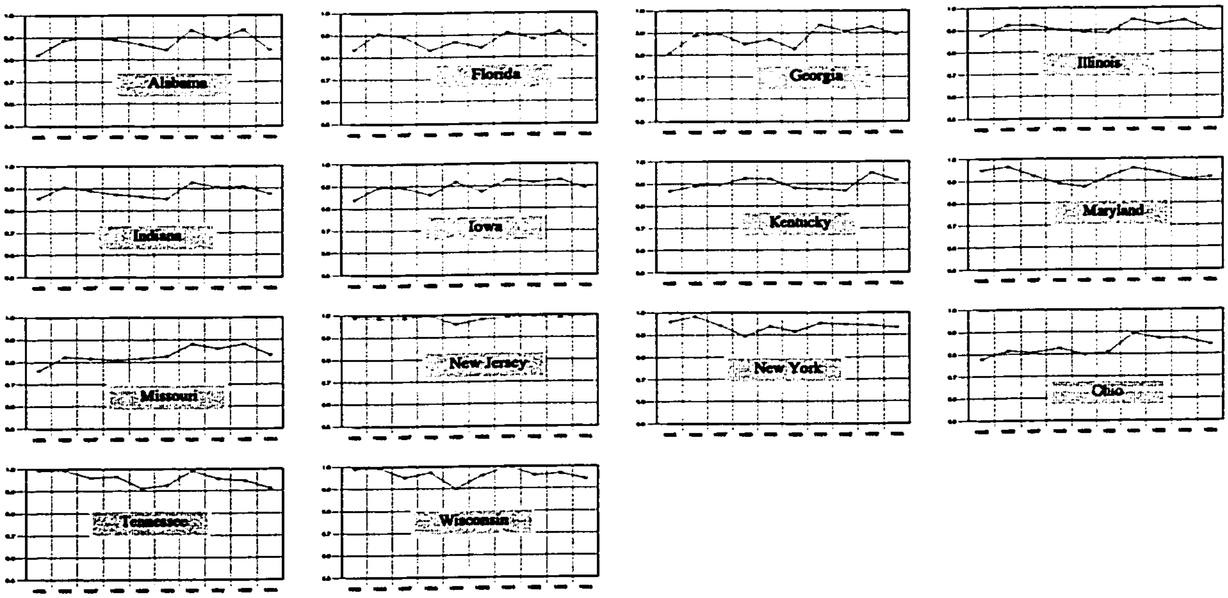
FIGURES

Figure 1: EFFICIENCY SCORES
(Averages Across States)
1985 - 1994

Technical Efficiency Scores
Averages Across States



Allocative Efficiency Scores
Averages Across States



Economic Efficiency Scores
Averages Across States

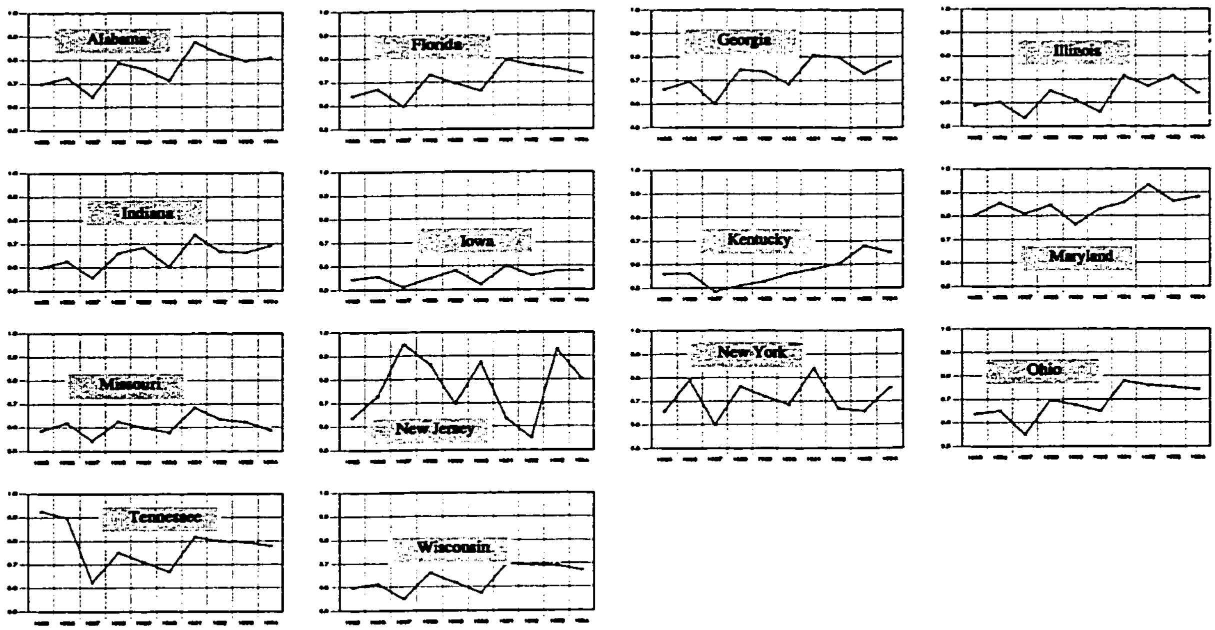


Figure 2: Efficiency Scores
(Averages Across Regions)
1985 - 1994

Efficiency Scores
Averages Across Regions

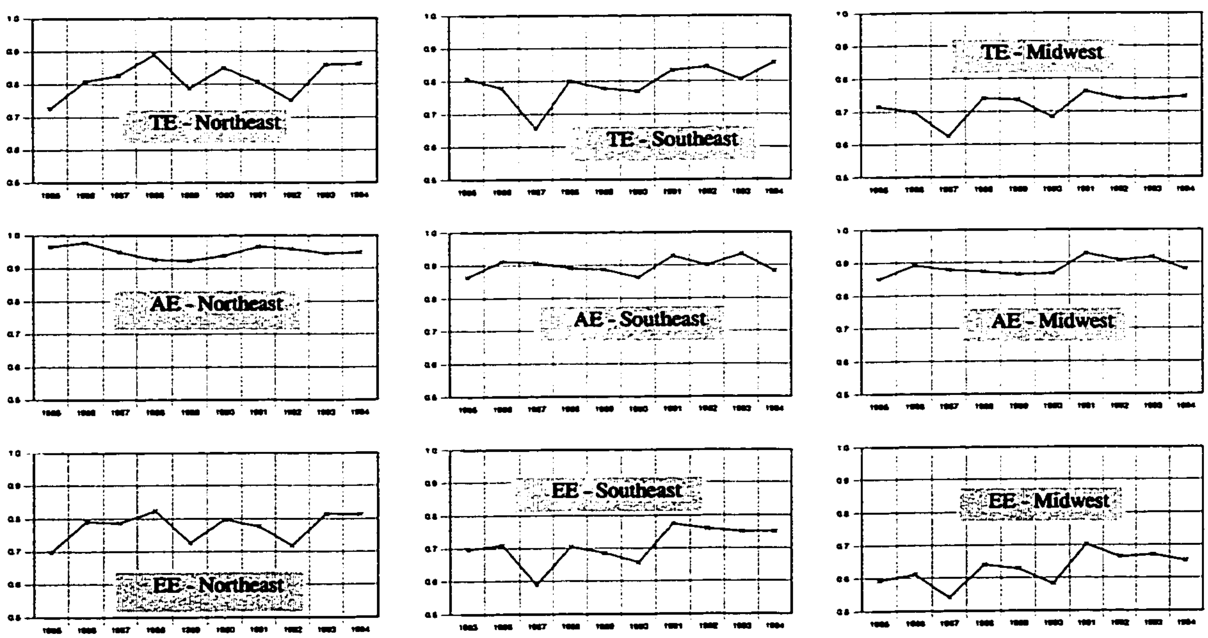
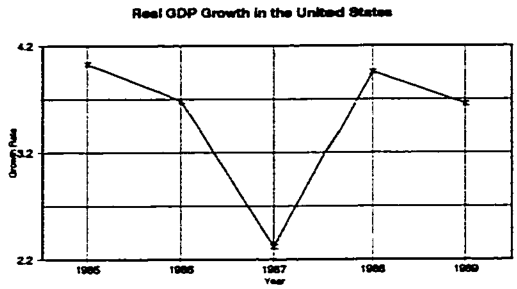
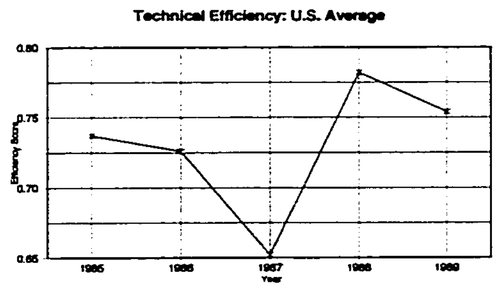


Figure 3

REAL GDP GROWTH AND TECHNICAL EFFICIENCY IN POWER GENERATION



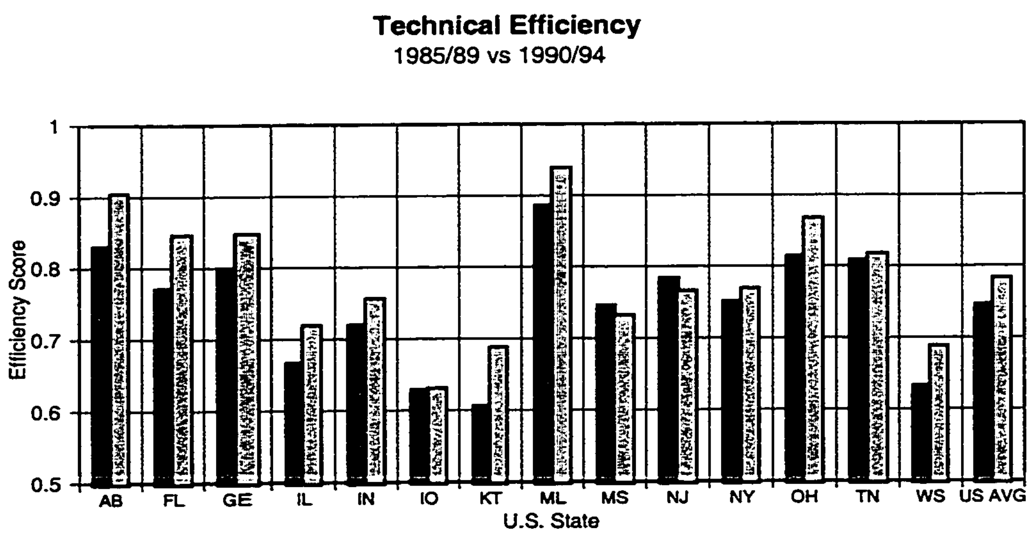
Source: U.S. Budget Office, Wasghington D.C.

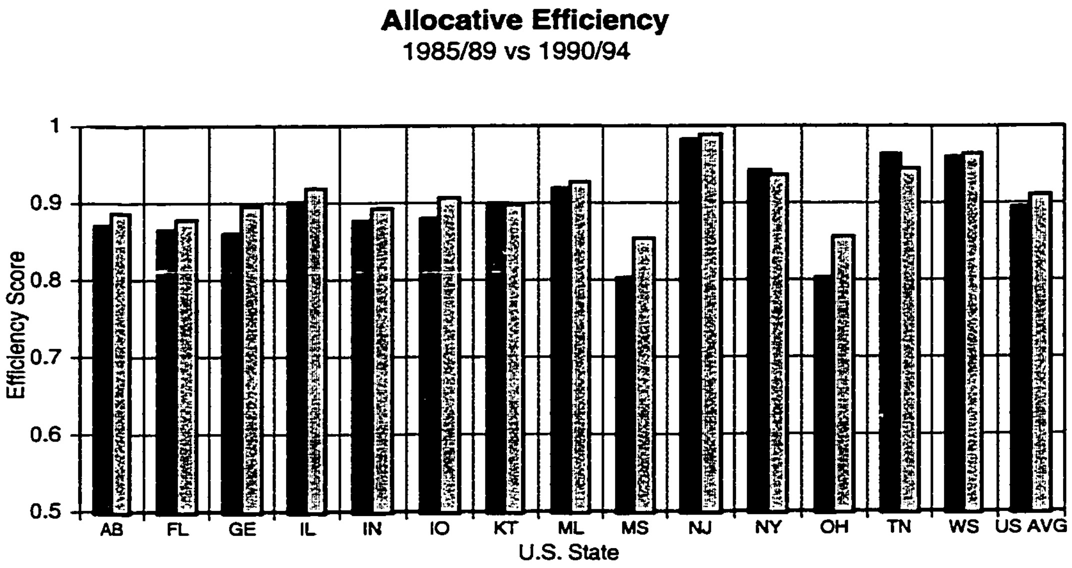


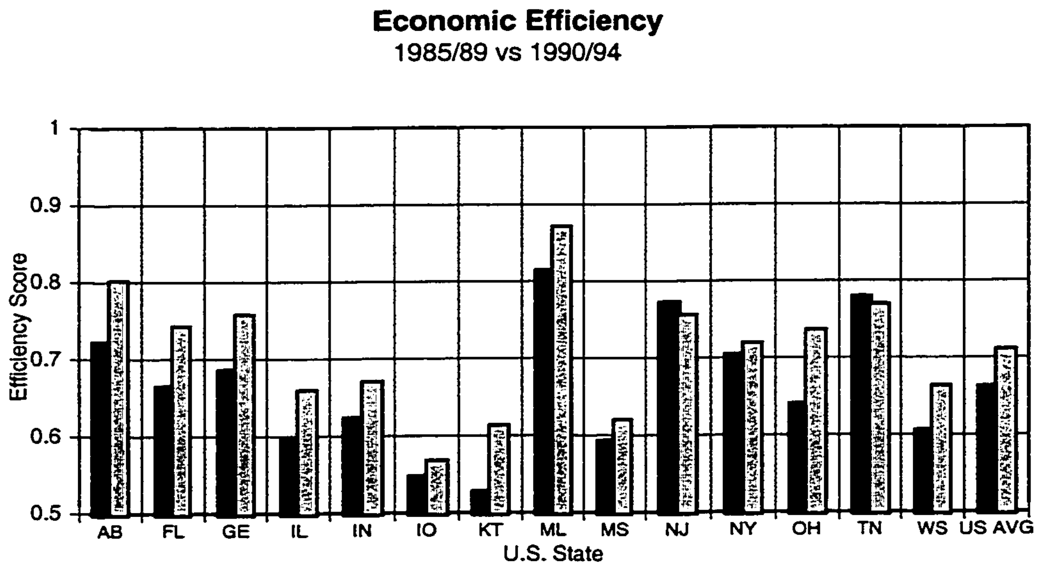
Source: Author's calcualtion

Figure 4

COMPARISON OF THE EFFICIENCY SCORES 1985/89 vs. 1990/94







Note: In all three graphs, the period 1985/89 is represented by 'black' bars, and the period 1990/94 is represented by 'grey' bars.