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EFFECT OF OWNERSHIP STRUCTURE ON EFFICIENCY: A COMPARATIVE ANALYSIS OF VARIOUS ORGANIZATIONAL FORMS

The Louisiana State University and Agricultural and Mechanical Col. PH.D. 1986

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EFFECT OF OWNERSHIP STRUCTURE ON EFFICIENCY:

A COMPARATIVE ANALYSIS OF VARIOUS ORGANIZATIONAL FORMS

A Disssertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

the Department of Economics

by
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This research is dedicated to my wife, Marie, who always believed in me. Without her constant support and understanding the completion of this dissertation would have been much harder.

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ABSTRACT

This research aims at testing the effects of ownership structure on efficiency of various organizational forms: privately-owned regulated electric utilities (PR), publicly-owned electric utilities (PU), and consumer-owned cooperative electric utilities (CO).

Because of the attenuation of their structure of property rights and high enforcement costs, it is expected that all three organizational forms (PR, PU, CO) will show some level of inefficiency. However, it is more difficult to establish which organizational form will be most efficient since all aspects of property rights are qualitative in nature. CO is expected to be more efficient than PR and PU since it shows: (a) more homogeneity of interest among principals; (b) more individual ownership claim over the assets; (c) a simpler political market (efficiency as the main issue of concern, and election every year); (d) a stronger monitoring structure when the control activity of the Rural Electrification Administration is considered. PU and PR cannot be discriminated and are expected to be as (in)efficient.

The methodology used to test for efficiency differences requires the selection of an appropriate estimator (stochastic frontier model), an objective function (cost minimization), and a functional form to capture the characteristics of technology (Cobb-Douglas production function) from which we can derive the economic models to be estimated (long and short run cost functions and a system of equations). Such a methodology is appropriate since it provides us with an absolute measure of mean technical and allocative efficien-

cies for each ownership structure considered. Those models are estimated using MLE and Davidon-Fletcher-Powell algorithm using data measured at the plant level from steam generating electric utilities.

The essential idea behind the stochastic frontier model is that the error term is composed of two parts: a symmetric component that permits random variation of the frontier across firms, and captures the effect of measurement error, other statistical noise, and random shocks outside the control of the firm; and a one-sided component which captures the effect of technical inefficiency relative to the stochastic frontier. Measures of allocative efficiency can be obtained from the residual of the first order conditions from cost minimization.

Results from estimation of those models indicate that: (a) all three types of ownership structures suffer from some degree of inefficiency; (b) estimations of long run models rank CO as the most efficient ownership structure; the difference between CO vs PR and PU is important and statistically significant, moreover, measures of inefficiencies of PR and PU are not significantly different; (c) estimation of short run models produces ambiguous results; the stochastic frontier short run cost function puts PR as the most efficient ownership structure while the system of equations shows identical inefficiency measurement for PR and CO with PU having the highest level of inefficiency; (d) total inefficiency is composed mostly of technical inefficiency for PR, PU, CO; (e) when efficiency measurement is compared for small and large plants, total inefficiency of large plants is nearly twice as much as inefficiency of small plants.

FIRST CHAPTER

INTRODUCTION

Over the last 20 years economists have been increasingly focusing their attention upon the nature of the firm. Even though most economists are basically familiar with the classical textbook definition of the firm, the renewed attention towards the nature of the firm brought into light concepts such as property rights, contracts among agents, transaction costs and efficiency. Alchian and Demsetz in their seminal paper (1972) argued that the ownership structure characterizing the entrepreneurial firm is endogeneous and has emerged to minimize the shirking problem facing all teams of production because of the transaction costs encurred to guarantee that contracts among parties involved will be respected. However, numerous types of organizations emerge and survive in market economies; aside from the traditional firms (the entrepreneurial firm), one can find modern corporations, multinational firms, regulated private firms, various types of partnerships, cooperatives, non profit organizations, publicly-owned firms, etc.. Very little is known about the nature of those firms; that is, how do they fit within the competitiveness of market economies, and more specifically, how does their structure of property rights relate to various measures of efficiency? Large sectors of the economy are characterized by the presence of different ownership structures, the agribusiness industry and the banking industry, for example, are two important sectors where private firms (often regulated) and cooperative firms compete with

each other on a large scale. Other sectors such as transportation, telecommunications and energy are characterized by the presence of public firms, private firms and cooperatives. Since most economists would argue that the economic system aims at an efficient allocation and use of scarce resources, the comparative efficiency of various organizational forms is an important issue to be considered since they are characterized by a different structure of property rights. This structure is thought to be related to efficiency since it affects the incentives to allocate resources to their most productive use, and the extent of exchange taking place in the economy.

The electric industry offers interesting features with respect to the central issue of this research. This industry encompasses several ownership types: private utilities (regulated), cooperatives, federal systems, and municipal utilities. The relative importance of each ownership type is as follows: the privately owned electricity generation accounts for approximately 77% of the total net generation in the United States compared to the publicly owned electricity generation which accounts for 21% of the total net generation, and less than 3% for the rural electric cooperatives (Sowell, 1978, p. 1). The importance of those ownership types varies with respect to the segment of the industry under scrutiny, but only the generating segment is of interest to us in this research. The primary energy sources for generating electricity are: coal (45%), oil (17%), gas (18%), hydro (15%), nuclear (5%) (Scott, 1976, p. 24). Only the conventional steam-electric power plants burning coal, oil, or

natural gas to produce heat which is used in converting water to high pressure steam will be considered. These fossil-fuel steam-electric plants dominate power production in the industry, and contribute to approximatly 80% of the total generation (Scott, 1976, p. 27). All ownership forms operate fossil-fuel steam-electric plants. Moreover, data on those plants are readily available and published yearly by the Federal Power Commission.

The central issue of this research is the comparative efficiency of various ownership structures. That issue will be addressed using the electricity industry because of the range of ownership types producing electricity using the same technology; each ownership type operates a sufficiently large number of plants to allow statistical analysis to be conducted.

There have been few studies to date which addressed this issue of cost difference between ownership structures in electric industry. Meyer (1975), Pescatrice and Trapani (1980), Dilorenzo and Robinson (1982) all estimated a cost function with a dummy variable accounting for ownership structure. Their results indicated that publicly owned electric utilities were more efficient than privately-owned electric utilities. Using a different methodology, a non-frontier cost function, Sowell (1978) concluded that private utilities were more efficient than public utilities. All those studies show methodological limitations; the use of a dummy variable model is based on the concept of an average function which does not represent the most efficient technology; it measures a combination of random shocks, technical and allocative inefficiencies, and it is not capable of

discriminating between them; furthermore, it implies that one of the ownership forms considered is efficient. Sowell's research concluded on comparative efficiency based on a comparison of average and marginal costs calculated for each ownership structure. His results are questionable since he did not control for technology differences across ownership types. Furthermore, they are contradictory since he claimed that both ownership forms showed duality between production and cost function (implying a cost minimizing behavior), but at the same time they showed allocative inefficiency.

The attenuation of the structure of property rights of each ownership structure along with their incentive and enforcement costs of monitoring is discussed in chapter two. The empirical models estimated on plant data from the electric utility industry, and used to measure and compare efficiency of those ownership structures are discussed in chapters three and four. They are comprised of : (1) a stochastic frontier function; (2) a functional form characterizing the underlying technology using a Cobb-Douglas production function; (3) an objective function characterizing the behavior of the various organizational forms where all organizational forms are assumed to be cost minimizers; (4) the models to be estimated which are a long run and short run production and cost functions; (5) the estimation is done with numerical techniques using MLE and Davidon-Fletcher-Powell algorithm. Such a methodology is appropriate because it provides estimates of absolute measures of technical and allocative inefficiencies for each organizational form. Results on measures of technical and allocative efficiencies for each ownership structure

are presented in chapter five. Our results indicate that all three organizational forms are inefficient to a certain degree. Furthermore, most models estimated indicate that cooperatives are most efficient compared to private regulated and public utilities. Differences, over mean inefficiency, among public and private regulated are not statistically significant. Moreover, estimates of total inefficiency are mostly comprised of technical inefficiency rather than allocative inefficiency.

The choice of an appropriate methodology to address this issue is of great importance. Among the models available, and reviewed in chapter three, we have selected the stochastic frontier model. From such a model, which can be used with a limited number of functional forms encompassing a production function, cost function as well as a system of equations, we derived information on absolute measures of technical, allocative and total cost inefficiencies for each ownership structure. Moreover, those estimates of various measures of inefficiencies have statistical properties allowing to test their statistical significance.

The debate over the efficiency of various organizational forms in the electric industry has been going on for almost a century. In 1907, the committee on Public Policy of the National Electric Light Association reported that:

> «the subjects of municipal ownership and public regulation and control of public utilities are intimately connected with each other. Neither can be adequately discussed without reference to the other. Indeed, one is the alternative to the other. Municipal ownership is demanded largely because of the

absence of proper public regulation and control. Public regulation and control, if efficient, removes the necessity or excuse for municipal ownership by securing fair treatment for the public (Hellman, 1982, p. 13).»

The performance of the electric power industry is still very much a controversial issue:

«fifty years ago vigorous debate centered on whether the role of government in this industry should be increased, with public enterprise replacing regulated private enterprise. Currently, in the wake of deregulation in other sectors of the economy, a central issue is whether the role of government in electric power should be reduced, with market forces replacing government regulation as the guarantor of acceptable industry performance (Joskow and Schmalensee, 1985, p. 5).»

Therefore, the analysis of the efficiency of the different organizational forms ought to be very important for policy matters.

SECOND CHAPTER

PROPERTY RIGHTS, INCENTIVE STRUCTURE, AND EFFICIENCY

1- Introduction

Two key demands are placed on economic organizations to be efficient (Alchian and Demsetz, 1972 p. 778):

(1) metering input productivity

(2) metering rewards

A specific reward system is needed to stimulate a particular productivity response. The property rights approach focuses on such a system of penalty-reward and its link with efficiency.

In the electricity generating industry we find three different types of organizational forms: the privately-owned electric utilities (PR), the publicly-owned electric utilities (PU), and the consumer-owned cooperative utilities (CO). Those various organizations can be distinguished on the basis of their property rights structure. Incentives of different parties involved; owners, customers, politicians, managers, input owners (other than stockholders), have to be assessed in relation with each given property rights structure.

Enforcement is crucial to link a specific system of property rights, and incentive, to a particular productivity response. High enforcement costs result in departure from the production-possibility and utility-possibility frontier (Pejovich, p. 344).

A proper definition and a presentation of the content of property rights is given in the second section of this chapter. In the third

section we focus on the specific penalty-reward structure attached to each organizational form identified in the electricity generating industry. A comparison of those structures will be conducted on the basis of:

(1) their property rights (attenuation of),

(2) the incentives of the various parties involved,

(3) the monitoring activities required to assure the respect of these rights (enforcement),

(4) the impact of the attenuation of property rights on efficiency.

Finally, a comparison of the various penalty-reward and their enforcement activities, will be conducted on the basis of their impact on efficiency.

2- Definition of property rights

Property rights can be defined as the effective right to do things, and the effective claim to rewards as a result of this action (Furubotn and Pejovich, 1972 p. 342). Three elements are recognized as characterizing the content of property rights:

(1) the right to use the asset (usus); i.e. exclusivity,

(2) the right to appropriate returns from the asset (usus fructus). It is the user's right to appropriate yield from an asset, and to bear the consequences from changes in the value of an asset, but not to sell or to change its qualities; i.e. appropriability,

(3) the right to change the asset's form and/or substance (abusus). It implies the right to legally transfer all rights; i.e. transferability.

Enforcement costs are crucial in establishing exclusivity, appropriability and transferability of property rights. Therefore, the costs of negotiating, contracting and enforcing the exchange are an important characteristic of property rights.

Since every contract means an exchange of some bundle of property rights, the attenuation reduces the set of opportunity choices of the contracting parties and affects the allocation of resources.

Attenuation interferes with two major propositions in economic theory:

(1) scarce resources tend to be allocated to those uses where they are expected to be the most productive,

(2) the extent of exchange depends upon the initial amount of goods in the possession of individuals and their marginal rates of substitution.

The definition of property rights has focused on its content, its fundamental characteristics, its attenuation with respect to the main propositions of economics, and the costs of enforcing those rights. The next section will focus on those aspects of the definition with respect to the entrepreneurial firm as a polar case, the privately-owned electric utilities, the publicly-owned electric utilities, and the consumer-owned cooperative electric utilities.

3- Description and comparison of various property rights structures.

In the property rights approach, attention is concentrated on the objectives of the various individuals involved in the organization. Different structures of property rights will lead to different penalty-reward, and hence determine the choices that are opened

to decision makers.[1] An analysis of the various structures of property rights requires both a definition of the utility function that reflects the preferences of the decision makers, and the actual set of options that are attainable by the decision makers.

The comparison of various structures (the entrepreneurial firm is added as a polar case) requires that we identify the different principals and agents involved in the decision making process, and establish their incentives[2]. The incentives of each principal and agent will have to be described with respect to the penalty-reward attached to each structure of property rights. The incentives will be influenced by the different attenuations of the property rights. Those attenuations will characterize the organizations as a limiting factor for the principals and agents in the pursuit of their own self interest. They will also affect the enforcement costs of property rights, allowing agents more room for discretionary behavior.

3.1 Entrepreneurial firm (polar case)

We classify the entrepreneurial firm as a polar case because it is thought to have none of the attenuations on property rights that affect the other three organizational forms (PR, PU, CO).

The firm, which is perceived as a nexus of contractual arrangements between input owners, is characterized by a non separable

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[1]Jensen and Meckling (1979, p. 472) state that the production of the firm will depend on the specification of rights and laws or rule of the game governing contracting. The relevant aspects of the contracting and property rights system within which the firm operates, play an important role in motivating self-interest to achieve the physically possible output.

[2]An agency relationship is defined as: a contract under which one or more persons (the principal(s)) engage another person (the agent) to perform some service on their behalf which involves delegating some decision authority to the agent (Jensen and Meckling, 1976, p. 308)

production function. With positive transaction costs (the cost of detecting, policing, monitoring and measuring input performances) each input owner will be induced to take more leisure time than when these costs are zero. Because of positive transaction costs, shirking becomes a viable activity.

Alchian and Demsetz (1972, p. 782) argue that the entrepreneurial firm, with its specific bundle of property rights, arises as a response to reduce shirking by constraining input owners to respect the terms of their contracts with the central party (the entrepreneur), who specializes as a monitor to check the input performances of the team members. To assure that the central party performs his monitoring task without shirking, he will be allowed to:

(1) measure input performance,

(2) apportion rewards,

(3) appropriate the net earnings of the team, net of payments to other inputs.

(4) terminate or revise contracts among input owners participating as team members.

The content of the property rights structure of the entrepreneurial firm can be rewritten with respect to the definition given in the previous section. The entrepreneur holds an exclusive right to use the assets since he represents the central party common to all input owners. He holds full claim on rewards by being allowed to appropriate the net earnings of the team, the residual. Finally, he holds full transferability rights since he can revise or terminate contracts among input owners. All fundamental characteristics of property rights are present in entrepreneurial firms: (1) exclusivity in the

use of the inputs, (2) appropriability of rewards, and (3) full transferability of those rights. The property rights structure characterizing the entrepreneurial firm is said to be complete.

The different parties involved with the entrepreneurial firm include: risk bearers (stock owners), managers, other input owners (labor, leased equipments, borrowed capital, etc.), customers[3]. The two functions of the central party, risk bearing and management of resources, are fulfilled by the entrepreneur[4] who will seek to maximize his objective function. Other input owners will also seek to maximize their own objective functions which are different from that of the management and risk bearer[5]. Their objective functions may include non pecuniary goods such, as on the job consumption of leisure time and respect as well as monetary income. This implies agency costs in carrying out the contracts agreed upon among input owners.[6] Non pecuniary income consumed by the agent, but not agreed upon by the principal in the contract, reduces profits of the

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[3]Customers are considered since they contract with the central party to buy output from the team of production. By seeking to satisfy their own interest they will play a central role in the overall incentive structure of the entrepreneurial firm.

[4]The management represents the one party who is common to all the contracts of the joint inputs, and who has the right to renegotiate any input's contract independently of contracts with other inputs. The risk bearer holds the residual claim and has the right to sell his central contract and his residual status owner. (Fama, 1980 p. 288)

[5]Jensen and Meckling (1976, p. 308) state that: if both parties of the relationship are utility maximizers there is good reason to believe that the agent will not always act in the best interest of the principal .

[6]Jensen and Meckling (1976, p. 308) state that: it is generally impossible for the principal or the agent to ensure, at zero cost, that the agent will make optimal decisions from the principal's viewpoint .

entrepreneurial firm affecting the oppportunity set of the principal. The monitoring activities[7] are required to enforce the bundle of property rights attached to the entrepreneurial firm. The principal (the entrepreneur) will enforce his rights to maximize utility up to the point where marginal gains of monitoring equals marginal costs of such activities. He derives his incentive to carry his monitoring activities from his full exclusivity, appropriability and transferability over the assets.

In the following sections, it will be shown that all attenuation of rights will reduce rewards that can be appropriate from monitoring and may increase the costs of monitoring. The results will be a set of expectations regarding the relative efficiencies of various organizational forms.

3.2 Privately-owned regulated electric utility (PR)

Property rights of the PR are attenuated because this organizational form shows separation of ownership from control. The risk bearer keeps the right to appropriate the net earnings as well as the right to sell all those rights. However, managers are given the rights, by the principals, to measure input performance, apportion rewards, and revise or terminate contracts among contracting parties. This attenuation reduces the ability of the owners to control the decisions made by the managers. Further attenuation results from the extensive regulation to which PR is subjected.

Each utility has been granted a monopoly franchise to construct facilities and provide power to a specified service territory. In

[7]Monitoring of contract agreements can be performed directly through budgets, policies, operating rules, ect.. It can also be performed indirectly through various input and product markets.

return for this monopoly power, utilities have ceded to regulatory authorities control over entry and exit from the business, over the rates that can be charged to consumers and over the amounts of profits that can be earned. This regulatory authority is exercised at two levels; the wholesale market, or sales between utilities, and the retail market, or sales to ultimate consumers. In general, federal authorities regulate the wholesale market, and the states regulate retail rates (Fenn, 1984, pp. 12-14). All activities of PR electric utilities outside federal jurisdiction are subject to state regulation. This regulatory authority is generally assigned to a state public service or public utility commission. At present, 11 states have elected utility commissions, while the others have appointed commissions. In addition to authority over retail rates, most state utility commissions have the authority to: (1) initiate financial and management audit, (2) set company performance standards, (3) establish automatic rate adjustment mechanisms, (4) and provide for consumer representation during regulatory proceedings. Many also have jurisdiction over such matters as accounting procedures, mergers and dispositions of property, financing arrangements, power plants and transmission line siting and utility expansion plans (Fenn, 1984, p.14)

Property rights of PR are affected by regulation. The exclusive use of the assets is being attenuated through the obligation to operate as a franchised monopoly and to meet demands in legally defined service territories. It also is attenuated by the regulation over wholesale sales and power pooling arrangements. Price regulation affects the right to appropriate returns from the assets. Transfera-

bility is also affected since decisions about plant expansion, type of generation or merger, are subject to regulation. Those attenuations affect the owner's expectations about the use to which he can put the assets since they make it more difficult to reallocate resources to more productive uses. They also affect the value of the assets to the owners. Finally, they create limitations on the owner's right to change the form, place or substance of an asset, and to transfer all of his rights to others at mutually acceptable prices.

The different parties involved with the PR are: risk bearers (stock holders), consumers, managers, other input owners (labor, leased equipments, borrowed capital, ect.), commissioners and politicians. Each of those parties will be maximizing its own utility function subject to the organization as a limiting factor. The attenuated property rights structure means that stock holders have limited rights over the assets because of regulation and separation of ownership from control. The regulatory commission may hold a large share of the property rights; and voters (consumers) control those rights through the political process, therefore, becoming one of the principals, along with the stock holders.

The overall structure of incentives is influenced by all these contracting parties. Stock holders are motivated by profits, but regulation limits their return on investment to a fair rate of return. The incentives of stock holders are reduced to zero after rate of return becomes effective since increased efficiency on the part of team members could not be appropriated or transferred. Consumers are interested in minimum prices and increased efficiency

in the use of resources. Their marginal gains from increased efficiency is therefore positive. Managers are influenced by the performance of the firm since it can be correlated to their opportunity wage. The evaluation of their performance can be accomplished indirectly by the managerial market, and directly by the board of directors. However, after the rate of return is effective, managers can appropriate potential profits at zero cost to stock holders. Managers are induced to consume non pecuniary goods such as larger staffs, larger gross assets, luxurious offices, less efficient but more desirable employees, etc.. Such consumption goes against the objectives of the principals since it deviates from the pattern that would ensure profit maximization or cost minimization. Managers may also lobby members of the regulatory commission about what are prudent costs, enhancing their potential consumption of non pecuniary goods. Only consumers would be affected. Non-capital input owners will also seek to maximize their own objective functions, which may be different from those of the managers or owners. On the job consumption may be included in their objective functions and attenuates the exclusivity and appropriability terms of the contract agreed upon by the parties. Politicians can also have their opportunity wage influenced by the performance of PR to the extent that it is recognized that they are not properly performing their task as monitors. But it will be even more difficult to correlate performances of politicians to this single efficiency issue. Therefore, assuming effective rate of return regulation, incentives for efficiency will depend mostly on the consumers.

The enforcement of the contracts among the team members is done by the principals (stock holders, consumers) over the agents (politicians, commissioners, managers), by the agents (politicians, commissioners) over the managers, and by the managers over the other input owners.

Stock holders have a strong interest in the existence of a financial market which prices the firm's securities efficiently. By having partial transferability rights over their ownership of PR, stock holders can indirectly monitor performances of the team of production. However, regulation affects the property rights structure of the firm through legal restraints on the allowable magnitude of the residual, limiting the ability to fully capitalize the future value of current decisions. This attenuation of property rights reduces the incentives of stock holders to monitor the performance of the team and to enforce the contracts among input owners and the central party. It also limits the efficiency of the financial market itself as a source of indirect monitoring. The market price for securities of private utilities is affected by the limitation over allowed rates of return. Potential expected profits of the firm would affect the security price under normal circumstances, but who would know if increased efficiency has not been pursued when profit is being regulated? More important, stock holders would not have any incentive in further specializing as monitors since they have no possibility of appropriating expected profit from such activities after the allowed

rate of return has been paid.[8] Voters (consumers) will indirectly control the performance of the team of production using the political process. By electing politicians who are committed to cost efficiency, voters can influence the decision process of the regulatory commissions. However, because of the free rider problem consumers are expected to shirk their task of becoming well informed with respect to efficiency of electric utilities and performance of politicians, and there may be less than socially optimal monitoring on their part. A final source of indirect monitoring comes from the managerial labor market. The performance of managers can be linked to their opportunity wage through the managerial labor market. However, the capacity of managerial labor market in evaluating performance of managers should be impaired the same way the financial market is; how do we know if managers are not performing optimally after rate of return regulation has been reached. Therefore, even though managers may not be seeking profit maximization or cost minimization it is unlikely that their opportunity wage will be affected.

Direct monitoring will be performed by the board of directors elected by the stock holders. They will directly evaluate the performance of managers in carrying out the contracts among input owners. The incentives of the board are likely to be the same as

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[8]We could envision the cost of monitoring the performance of the team as being function of the efficiency of the financial market until the allowed rate of return has been reached. After that point there is an expected increase in monitoring costs since information over potential increased efficiency has no value to stock holders and is not likely to be accounted for by the financial market. Interested parties would have to rely on direct monitoring to find out about potential increase in efficiency not captured by the team of production.

those of the stock holders, and they are likely to be limited the same way. Therefore, stock holders will tolerate discretionary behavior on the part of management since it is virtually costless (to managers and stock holders) to transfer potential profits over and above the allowable rate of return. Stock holders will monitor managers to the point where marginal costs of monitoring equals marginal gains of such activities. After the allowable rate of return has been paid, marginal gains to stock holders virtually fall to zero while the marginal costs increase because of the limitations imposed on the indirect monitoring activity performed by the financial market. The regulatory commission will also be directly monitoring the performances of the production team. Their incentives come from the political process. They may have access to some of the information that the board of directors has, information that managers have to provide by law and when asked for it. But it is unlikely that they would have as much information on the privately-owned utility than the board of directors has, since the regulatory commission is specifically asking for information when it is conducting hearings while the board is actively involved in the operations of the PR. Furthermore, it is not in the best interest of the PR to provide more information than is required by the regulatory commission. However, the possibility of comparing the performances of various utilities allows for the indentification of sources of

inefficiencies at low cost.[9] Finally, managers will be monitoring activities of other members of the team. Regulation allows more freedom for managers to have discretionary behavior as long as they perform well enough to pay the allowed rate of return. Other sources of monitoring, such as direct market competition, are not likely to be of much help since private utilities are franchised monopolies. Furthermore, the possibility of a take over should be limited since the Federal government regulates such activities. However, potential competition may be a positive force.

In conclusion, attenuation of property rights of PR affects the incentive structure by reducing potential marginal gains of the principals and agents involved as well as increasing the enforcement costs. When rate of return regulation is effective, incentives of stock holders fall virtually to zero. Appropriability of consumers is attenuated. Furthermore, consumers have to face high enforcement costs to appropriate residuals (cost of production - minimum cost of production) since they have to rely on two sets of agents to do so. Finally, the regulatory commission is arbitrating among various interests of consumers, stock holders and managers, further increasing the enforcement costs of consumers to appropriate more residuals in the form of reduced prices. Consumers have almost no transferability other than reducing the amount of electricity bought. Only stock

[9] Joskow and Schmalensee (p. 21) state that: The availability of such comparative statistics could make regulation more effective. And if the regulatory authorities made extensive use of such comparisons, this form of competition could represent an important implicit source of rivalry between monopoly firms. Despite the prominent role that yardstick competition has long played in discussions of public policy toward electric power, until recently regulatory agencies do not appear to have made much use of comparative information.

holders can transfer claims over the assets of PR. Therefore, attenuation of property rights affects the efficiency of indirect control since the financial and managerial markets will be less effective after rate of return regulation has been reached while the political market may produce less than optimum monitoring because of the free rider problem. Since regulation eliminates much of market competition, there may be less indirect monitoring by potential competitors than for the entrepreneurial firm. Efficiency of direct monitoring is also likely to be affected since the board of directors has reduced incentives to further control activities of managers while the regulatory commission is likely to intervene at times of hearings and based on informations mostly given to them by the managers of PR.

3.3 Publicly-owned electric utilities (PU)

Municipal systems are usually run by the local city council or an independent board elected by voters or appointed by city officials (Fenn, 1984, p.10). Some of the state commissions are empowered to regulate municipal electric systems. However, they usually do not exercise all their powers over municipal systems because of inadequate staff and funds and the willingness to invade the autonomy of municipal governments (Power committee, 1948, pp. 425-426).

The PU shows separation of ownership from control, but contrary to PR, further attenuations of its property rights are not caused by regulation. The main difference comes from the fact that ownership is obtained with residency. Voters cannot buy or sell portions of stocks in the government; i.e. transferability of ownership cannot be done through the financial market. Residents who want to sell their shares

of the utilities have to migrate from the area, reduce their quantity of input bought, or sell the entire utility to a third party. Transferability of ownership (to a third party) could be translated in terms of reduced taxes or allocated to other uses within the municipalities. Transferability is further affected by the limited rights of owners to sell their assets; they cannot directly sell their claims on future cash flows. Even though the residual is likely to be zero by law, the potential gains from increased efficiencies are the reduced costs to residents, so appropriability of rewards from actions that would lead to increased efficiencies are well identified. Moreover, price of electricity is likely to be charged close to its cost, so that consumers would notice the impact of improved efficiency. Appropriability is limited since residents can benefit from increased efficiency only proportionally to their level of transaction with the utility. Only if they benefit from the assets for a sufficiently long period will they be able to appropriate future expected benefits from current decisions.

The different parties involved with the PU are: owners/users (residents), politicians, managers and other input owners. As before, each of those parties will be expected to maximize its own objective function. The incentives of the residents are derived from the use of electricity. Users would benefit from a price reduction following an increase in efficiency of the production team. Since politicians are elected to efficiently allocate resources in the public domain, the inefficient use of public resources is likely to reduce their chances of being reelected. Moreover, like managers and the managerial labor market, politicians who are not seeking reelection have to

consider the possibility that their opportunity wage would be affected by bad performances as managers of public resources. Managers of PU may have much the same objectives as their counterparts in PR, where pecuniary as well as non pecuniary income enter their objective function. As in the PR, attenuation of property rights allows them discretionary behavior, such as larger staff, less productive but more desirable employees, larger assets, etc.. Attenuation reduces potential penalties for not seeking more efficient projects, for not monitoring other input owners properly, etc.. Potential penalties come from evaluation of their performance by politicians and residents, and from possible impact of bad performances on their opportunity wage. Other input owners also have pecuniary as well as non pecuniary goods entering their objective functions and therefore, can be expected to shirk on the terms of the contracts among parties.

The overall structure of incentives derived from the property rights of PU is towards increased efficiency because of user/owner objective of cost minimization. However, attenuated rights of these principals allow some discretionary behavior on the part of the agents, politicians, managers and other input owners; so deviations from the patterns of cost minimization are to be expected.

The enforcement of the contracts among the team members is done by the principals (residents) over the agents (politicians, managers), by the politicians over the managers, and by the managers over the other input owners. Indirect monitoring by the residents will be performed using the political system. By electing politicians, who nominate directory board members, committed to efficiency in the use

of resources, voters will indirectly monitor the activities of the team of production. In order to perform their monitoring task properly, voters need to know about preferences of politicians over efficiency issues. Furthermore, they need information about the relative efficiency in PU; i.e. in producing electricity in order to evaluate the performances of politicians. Because politicians are elected over a wide variety of issues, they will unlikely monitor utilities perfectly. Furthermore, the free rider problem suggests that voters are likely to shirk their task of being well informed on preferences of politicians or on politicians' records with respect to efficiency of electricity generation. Indirect monitoring by residents can also be performed by observing areas serviced by other utilities.

Politicians and the board of directors of the PU will be directly controlling the activities of managers. Information will be obtained from the management and other input owners; but compared to regulators of the PR, politicians and directors may not have as much information about several utilities. However, just as in the case of the PR they may have information coming from potential competitors. Unlike the regulatory commission, the board of directors of the PU will be actively involved in supervising activities of managers, and they will have to consider interests of the consumers.

The managerial labor market will control managers to the extent that their performance affects their opportunity wage. But there is no reason to expect that managerial labor markets will pressure managers of the PU any more than those of the PR.

In summary, important aspects of the property rights structure

are attenuated, thus affecting the incentive structure dominated by consumers' objectives. Because of limited appropriability and transferability, consumers cannot expect full rewards from actions that would enhance efficiency. Rights are further limited by the enforcement structure. The political system is likely to be inefficient with respect to utility alone since politicians can shirk their task of monitoring efficient use of resources within PU. They are elected over many issues and for a four-year period. Furthermore, voters are likely to shirk their task of being properly informed about such issue as efficient electricity production.

3.4 Consumer-owned cooperative utilities (CO)

The rural electric cooperative is an incorporated association of neighbouring farmers and other rural residents, organized democratically for the purpose of supplying electricity to its members at the lowest cost made possible through mutual self-help and the Rural Electrification Administration's (REA) financing and guidance. Electric cooperatives are almost entirely financed by the federal government who closely supervises and assists the establishment and the operation of their businesses (Power committee, 1948, p. 451). The contract, which governs the relations between the REA and the cooperative after the system is in operation provides REA with the needed information to supervise all major aspects of the operating policy. Operations are supervised through ten (10) regional supervisors, and co-ops must submit annual and monthly operating statements and statistics. The REA has no congressional mandate to regulate the retail rates of cooperatives, but the cooperatives must charge rates sufficient to pay taxes, maintenance costs and other operating

expenses, to meet principal and interest charges when due, and to provide a reasonable reserve for working capital. In practice, REA virtually determines the retail rate policy of the cooperatives (Power committee, 1948, p. 455). In most states, cooperatives are not subject to state authority (Power committee, p. 460).

Therefore, a cooperative is a non-profit economic entity, usually found operating at the retail level which is owned and managed by its customers. While cooperative members hold shares in their cooperatives, these shares do not generate dividends for profit, but are reinvested into the operation of the business as patronage capital, which is often credited to individual members. Cooperatives operate on a one-person, one-vote basis and the members elect directors from their own ranks (Doyle, 1979, p. 2). The rural electric system is a two level operation, comprised of some 980 local distribution co-ops and approximatly 60 generating and transmission co-ops (G+T's). Local co-ops distribute electricity to their own rural customers, while G+T's generate and/or transmit electricity primarily for local distribution co-ops, which are typically members of a G+T's or a co-op federation (Doyle, 1979, p. 15). Co-op democracy is a representative democracy, and at each level of co-op decision-making, the local co-op is represented by one of its board members or its directors. Local co-ops have typically at least one of their board members on the boards of the state rural electric association and the G+T system to which they belong (Doyle, 1979, p. 203)[10].

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[10]Doyle goes further by saying that many of the local representatives on the G+T boards depend on the G+T staff expertise and management assessements of policy issues to help them decide how to vote at boards' meetings (1979, p. 203).

Cooperatives are private organizations with open membership. However, ownership of a cooperative is related to the usage of its services. An ownership share is paid in part with an initial fee called social share. Further investments are made through undistributed residuals; patronage capital on which members have individual claims. This additional investment is related to the transactions made by the members with the CO.

Even though there is no financial market for claims of the cooperative shares, which will limit transferability, members have a claim on cash flows contingent on being a user and they can appropriate expected increased efficiency through reduced price of electricity. Appropriability over the cash flows of the CO covers the full price paid for electricity as well as the residual which is a percentage over operating prices until all costs are accounted for. Appropriability is limited to the level of transactions between the cooperative and its members. Because ownership is limited to one share, members cannot expect to appropriate (full) rewards from actions that would result in increased efficiency. However, appropriability is further attenuated because members will not be able to bear the consequences of changes of forms and substances of the assets, and the future consequences of improved management will not be directly capitalized into present wealth of claim owners although they may be capitalized into other assets, such as land values. Unless they remain members long enough to use up the assets, they are expected to suffer from the horizon problem related to their expected termination (i.e. migration) date (as owner of a claim over the cash flow of the co-op). Finally, the role played by the REA, even if it

does not have a congressional mandate to regulate the rural electric cooperatives, attenuates appropriability since it virtually determines their retail rate policy. Ownership claim, comprised of a social share and the patronage capital credited to members, can only be sold back to the cooperative at nominal value, which attenuates transferability over claims owned by members. The absence of financial market forbids transfer of rights at market value. When members transfer their ownership claim to the coop, they can act merely as consumers. Transferability is further attenuated since the co-op cannot change the form and/or substance of its assets without approval by the REA.

The principals for the CO are the members, and to a certain degree the voters since the Federal government (representing the voters) finances almost entirely their operations. The contract which governs the relations between the co-op and REA covers all aspects of their operations. The agents are the board of directors, the managers and the REA officers (representing the Federal government). The incentives of the members are derived from the use of electricity. Cost of production will directly enter their objective function, as will the size of the residual that can be distributed at the end of the year. The board of directors consists of members as well, so they should have much the same incentives as the members themselves. Aside from the social value of the rural electrification program, voters ought to be concerned with respect to the possible default in cooperative loans since the Federal government is responsible for almost all the money borrowed by the co-ops.

Managers and other input owners may have the same objective functions as the managers of the PR and PU. The incentives influen-

cing managers are related to their expectations with respect to their opportunity wage determined in the managerial labor market. They are also induced to consume non pecuniary goods as were managers of PR and PU utilities. Bureaucrats from the REA agency also have an objective function in which enters pecuniary as well as non pecuniary income since they are managers for the Federal government.

The incentives derived from the co-op's property rights structure are based on both electricity prices and potential residuals. Claims over the assets, even though limited, will also influence members since they can withdraw from the co-op and expect to be bought off. The REA supervises the activities of the co-ops in order to reduce risk of bankcruptcy. Their incentives might lean more toward sufficient revenues than minimum costs. Indirect control over the activities of the team of production is rather limited. Since there is no market to exchange the assets of the CO, members can only sell their share to the co-op itself, or migrate. In the absence of migration they still would have to buy electricity from the co-op since it is most likely to be a franchised monopoly within a specific territory. Since cooperatives are not regulated, members cannot delegate indirect control of agents to politicians. They could sell off the assets of the CO and divide the proceeds among themselves. Members elect directors annually at a general assembly. They indirectly control the agents by delegating their responsability to the directors. Therefore, indirect monitoring is performed by a political system where the politicians (directors) are elected every year over a single issue; efficient allocation of resources. This may be a major difference with respect to PU. Direct control is performed

mostly by directors who oversee the performance of managers. Information comes from the production team. The board may not have as much comparative information as the regulatory commission, though information is available via the Federal Power Commission and the Rural Electric Administration, but like the PU it has inside information with respect to the activities of managers. Furthermore, direct monitoring is performed by the bureaucrats of the REA who have extensive powers over the operations of the co-ops. REA has information on a large number of utilities. The role played by the REA, as a monitor, is a major difference between the CO vs the PR and the PU.

In conclusion, attenuation of property rights affects incentives of consumers; appropriability is limited to the level of transactions of members with the co-op, furthermore, it is limited since members cannot appropriate expected future residuals unless they remain consumers long enough. Transferability is limited by the absence of financial market and the obligation to sell off claims over the assets of CO to the co-op at nominal value. Incentives of members are centered on reduced prices. The role played by the REA is important and will enhance the incentive structure of the co-op. Indirect monitoring takes place through the political market; this political market is private since CO have open membership with democratic representation. Board members are elected over a single issue every year and control the activities of the CO directly. Monitoring is also performed by the REA on a regular basis. The role of REA both in the incentive structure (as lender) and the monitoring structure seems to be a major difference with respect to PR and PU.

4- Comparison of efficiencies of organizational forms (PR, PU, CO)

4.1 Meaning of Efficiency

Efficiency is a complex concept:

«it is a statement about the performance of processes transforming a set of inputs into a set of outputs. It is a relative concept since the performance must be compared to a standard».[11]

This standard will be strongly influenced by the characteristics of the technology including all feasible physical possibilities. The characteristics underlying a technology are best represented by:

(1) the scale effect; the relative increase in output as all inputs are increased proportionally. The technology can show increasing, decreasing or constant returns to scale. If the marginal rate of technical substitution between inputs remains unchanged as output increases with input proportions constant, we have a homothetic technology.

(2) the substitution effect; the degree to which inputs can be substituted for one another. It refers to the shape of the isoquants.

(3) the expansion path; it is defined as the locus of cost-minimizing input combinations in input space for a given set of input prices.

(4) the technical change; it is generally recognized that the production technology changes over time. Technical change will shift the production function, and the nature of the shift will determine whether it has a neutral or non-neutral

[11] Forsund and Hjarmarsson (1974, p. 141)

effect on the inputs of the production process. A non-neutral change means that one or more of the factor inputs has become disproportionally more productive than the remaining inputs.

The concept of technical change requires a distinction between ex ante and ex post technologies. The ex post technology represents a specific technology in place, while the ex ante technology represents the set of all available blueprints for equipment of different design characteristics prior to installing a new piece of equipment. The technical change is said to be embodied when only the new equipment can incorporate the most recent technology. It is said to be disembodied when technology is influenced by phenomena like learning by doing whereby productivity of old inputs are affected.

Establishing a meaningful hypothesis as to which organizational form is expected to be more efficient first requires a definition of efficiency. Static measures of efficiency can be divided in three categories:

(1) technical efficiency requires a firm to produce a maximum level of output from a given input bundle[12]. The firm will therefore be on its production frontier.

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[12]In general, two different measures of technology can be defined. The first measure shows the ratio between the amounts of inputs required to produce the observed output with frontier technology, and the observed amount of input. This input saving measure shows the relative reduction in the amount of inputs needed to produce the observed output, with frontier technology, using the observed factor production. A second measure is obtained by comparing the observed output with the output obtained on the frontier using the same amount of inputs. This output augmenting measure is the ratio between the observed output and the potential output obtained by employing the observed amounts of inputs in the frontier production. These two measures will coincide in the case of linear homogeneity.

(2) allocative efficiency requires a firm to utilize its inputs in the right proportion, given input prices[13]. The firm is operating on its least-cost expansion path.

(3) scale efficiency requires a firm to operate at the appropriate scale level for a given vector of inputs[14]. The scale level is appropriate when the size of the plant shows the average short run cost curve tangent to the minimum point on the long run average cost curve.

The *frontier production function corresponds to maximum output* given by the technological possibilities at the time of installation of the latest equipment. It is a planning frontier, or an ex ante function. The actual possibilities for a plant at a given moment in time are determined by the vintages of all the existing production units. Therefore time introduces problems in measuring efficiency in two ways:

(1) A plant could be designed and utilized at its inception in a manner in which there are neither technical nor allocative inefficiencies; i.e. it is on its planning frontier. At a later time, it could be off the current frontier for two reasons:

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[13]Allocative efficiency is represented by the point of tangency between an isoquant and the relevant isocost line.

[14]The measures of scale efficiency refers to the output augmenting measure if the maximum average product is applied to the given scale, it refers to input savings if a given output was produced at the maximum average product. In order to control for technical inefficiency, those measures compare the optimal plant scale to the hypothetical output or input requirements if the firm was on its frontier. For this reason, a constant returns to scale production frontier would exhibit no scale inefficiencies.

a) technical change shifted the frontier, so while the plant may be on its ex ante frontier, it is not on the current frontier.

b) factor prices may turn against the firm even if there is no technical change. If technology is not putty-putty it cannot readjust fully and allocative inefficiency is observed.

(2) There may be some optimal adjustment path in response to changing technology and prices over time, determined by the firm's objective function.

Even though we can do little to control for the second problem, we can control for the first by considering only new plants and specifying vintages.[15]

Recognizing the characteristics of technology in the electricity generating industry is very important in order to be able to interpret the various measures of inefficiencies. Technology used to generate electricity is said to be of the putty-clay type[16]. This is important since as it is argued by Fuss and McFadden (1974 , p. 317-318),

«in the presence of significant flexibility efficiency trade off, conventional econometric production functions provide very little information on the structure of the ex

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[15]Fuss and McFadden (1974) suggest estimating models of the firm in which an ex ante decision is made on plant design, based on expectations about the environment to be faced ex post. (pp. 320-321). This kind of model allows a recognition of the possibilities of a trade off between flexibility and efficiency.

[16]A putty-clay technology can be represented by an ex ante design that achieves static efficiency at some output, and fixes the quantities of both capital and variable inputs in the ex post technology.

ante best practice envelope curve, and may indeed provide misinformation. More fundamentally, we conclude that the concept of a static best practice envelope curve characterizing the ex ante technology is inadequate, and in environments where firms face considerable uncertainty and intertemporal variation, irrelevant. It is in this case impossible to define meaningful isoquants in a static picture of one-period production possibilities in which the flexibility-efficiency trade off has no explicit representation.»[17]

If such is the case, then our standard of comparison to measure efficiency has to be carefully interpreted even in dealing with data representing ex ante technology.[18]

In a putty-clay world where some input substitution becomes impossible until the next plant is built, changing prices of inputs will make the firm appear to be allocatively inefficient. However, this may not be neccessarily the case. For example, we can't ignore the cost of adjustment. Also managers could have included such things as flexibility-efficiency tradeoff in the planning frontier, or they

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[17]Examples of flexibility-efficiency decision in production processes are: (1) Electric utilities can build base load plants which have higher capital cost, but lower operating cost, and represent the lower cost technology for providing continuous output, or they can build peak load plants. (2) They can also build thermal plants which can be converted to use oil, gas or coal. These boilers increase capital and maintenance costs and thus result in inefficient production if only one type of fuel is used throughout the life time of the plant. (Fuss and McFadden, pp.311-312)

[18]Since we are interested in a comparative analysis of various organizational forms, we can hypothesize that their ex ante and ex post environments are sufficiently comparable to allow meaningful comparisons. However, all comments about absolute inefficiencies with respect to each organizational forms have to be very carefully interpreted.

may expect changes in relative prices of inputs later and plan to be allocatively inefficient in the early stages.

4.2 Attenuation of property rights and efficiency

As it has been stated earlier, the two major propositions of economic theory are: (1) resources are allocated to their most productive use, (2) and the extent of exchange depends upon the initial amount of goods in the possession of individuals and their marginal rate of substitution. Attenuation of property rights : (1) affects the owner's expectation about the use to which he can put the asset, (2) affects the value of the assets to the owners and to others, and consequently the terms of trade, (3) implies the existence of limitations on the owner's right to change the form, place or substance of an asset, and to transfer all of his rights to others at mutually acceptable prices. When incentives are limited because of attenuation of property rights, or because of high enforcement costs, it is less likely that resource owners will be motivated to trade optimally. Property rights are defined as one's effective right to do things ((re)allocate resources to more productive uses), and one's effective claim to rewards as a result of his action (affects the MRS_{xy} and therefore the extent of exchange). Attenuation of property rights can be translated in terms of lack of incentives to meter input productivity properly, or to apportion rewards accordingly. The absence of correlation between input productivity and rewards will leave the economic organization to be inefficient. High enforcement costs will reduce the amount of monitoring for all level of incentives from property rights, and shirking among resources owners will be more viable. The value of goods (function of the bundle of property

rights attached to it) will be decreased, and less exchange will take place.

The entrepreneur has exclusive rights to use the assets, full claim on rewards, and full transferability. Therefore, he has full incentives to monitor and to enforce contracts among members of the team of production. Those rights will allow the entrepreneur to maximize its utility function. He will enforce those rights directly by observing and measuring performances of members of the team. He will be forced to perform his monitoring task otherwise competitors would cease opportunities and consumers would vote him out of the market (or he would have to reduce the residual that he can appropriate after all input owners have been paid).

The entrepreneurial firm produces maximum incentives to monitor input performance (property rights are said to be complete), and reduces the enforcement costs of monitoring those activities. Since entrepreneurs are utility maximizers, they will be expected to maximize the rewards from appropriability and transferability, and therefore, correlate productivity and rewards (to resource owners). We can expect that resources will be allocated to their most productive uses.

All three organizational forms presented earlier are not expected to be efficient since they all suffer from attenuation of property rights and high enforcement costs which affect the overall incentive structure of the principals and agents involved.

4.3 Comparative efficiency of PR, PU, CO

Table 1
Comparison of efficiency of PR, PU, CO
Summary

	PR	PU	CO
INCENTIVES			
1) Owners of PR when (0<z<1) PU, CO			
. exclusivity	–	–	–
. appropriability	–	–	+
. transferability	–	–	+
2) Consumers of PR, PU, CO			
. exclusivity	–	–	–
. appropriability	+	+	+
. transferability	–	–	–
CONTROL			
a) Indirect			
1) Financial market (0<z<1)	+	–	–
2) Managerial labor market	+	+	+
3) Political market	+	+	++
b) Direct			
1) Board of stock holders (0<z<1) vs directors of co-ops and directors of municipal system	+	+	+
2) Regulation (Regulatory commission vs REA)	+	–	+++

A comparison of efficiency of those organizational forms is very difficult to establish. All three forms show attenuation of their property rights structures which impaires their overall incentive and enforcement structures. From the summary table 1, it is seen that incentives derived from the property rights structure for CO seem a little stronger since members have more appropriability (the residual) and transferability (the claims over social shares and undistributed residual). Looking at consumers (as principals)[19], their incentives towards increased efficiency seem very much alike. From

[19]We must recall that consumers of co-ops are also members while consumers of PU are also residents.

the enforcement structure point of view, CO seems to come first because its political market deals with a single issue while elections are on a year basis. The main advantage however comes from the control by the REA bureaucrats since these have to protect the Federal Government from Co-op's default on loans, and are doing so by supervising all aspects of cooperative's administration.

In concluding however, one has to emphasize the limitation of such comparison because of the qualitative nature of the various dimensions used to characterize each organizational form.

THIRD CHAPTER

LITERATURE REVIEW ON EMPIRICAL MEASUREMENT OF EFFICIENCY

1. Introduction

This chapter reviews the literature on empirical measurement of efficiency. Several models have been proposed to measure efficiency. They can be categorized as follows: (1) deterministic non-parametric frontier, (2) deterministic parametric frontier, (3) deterministic statistical frontier, (4) stochastic frontier model, (5) non-frontier efficiency models, (6) total factor productivity, (7) dummy variable model. Each of those models has advantages and disadvantages. A discussion of those models with respect to the objective of this study follows in section 2 and a review of empirical results relevant to this study is made in section 3.

2. Quantitative measures of efficiencies : review of the various models developed and used to test and measure efficiency

2.1 Deterministic non parametric frontier

Following Forsund et al. (1980, pp.8-9),

«Farrel's approach is non-parametric in the sense that he simply constructs the free disposal convex hull of the observed input-output ratios by linear programming techniques. It is not based on any explicit model of the frontier or of the relationship of the observations to the frontier»

Farrel's (1957, pp.254-255) measure of technical efficiency is calculated from a best practice technology one can observe. The efficient isoquant is derived from an efficient production function obtained from observations of the inputs and outputs of a number of

firms. Each firm is represented by a point on an isoquant diagram. From the scatter diagram, the efficient isoquant is estimated, and the pairs of points chosen are those for which the line joining them satisfies the two following conditions: (1) the line must be downward sloping, (2) no observed point must lie between it and the origin. The isoquant represents the various combinations of the two factors that a perfectly efficient firm might use to produce unit output. The efficiency of a firm (represented by a point above the efficient isoquant) is measured by comparing it with a hypothetical firm which uses the factors in the same proportions. Farrel tested his technique using U.S. agricultural data over 48 states with one output (cash receipts from farming) and four inputs (land, labor, material and capital) each of these variables being represented as the input of a particular factor per unit of output (1957, p.269). His results show that 20% of the states are 100% efficient, 9% are between 90-100% efficient, 30% are between 80-90% efficient, 25% are between 70-80%, 13% are between 60-70%, and 3% are between 50-60% efficient.

The advantage of Farrel's technique is that no functionnal form has to be imposed on the data. The disadvantages are that constant returns to scale (CRS) is restrictive, the extension to non-CRS technologies is cumbersome, the frontier is particularly sensitive to extreme observations and measurement error, and the estimates which it produces have no stastitical properties.

2.2 Deterministic parametric frontier

Recognizing that the frontier production function forms the core of microeconomic theory, Aigner and Chu (1968) outline an empirical framework within which this frontier is observable. The authors

define an industry function which resembles Farrel's efficient production function[1]. Though they go further by estimating with mathematical programming (linear and quadratic) a production function for the firm that expresses the maximum output obtainable from the input combination at the existing state of technical knowledge. Linear programming produces the envelope function by controlling the disturbance term to be of one sign only. The objective function appears as the summation of such disturbances and it is to be minimized subject to the constraint that each residual be non-positive.

Aigner and Chu start out with a Cobb-Douglas production function as specified by Hildebrand and Liu (1965). They derive the criterion function which they pose in a typical programming problem.[2] Even though they do not refer to measures of efficiency, the technical efficiency of each observation can be computed directly from the vector of residuals since $u = \ln f(x) - \ln(y)$ represents technical efficiency. Since their technique is based on the estimation of a production function, it is impossible to obtain an estimation of allocative efficiency. Forsund and Hjalmarsson (1979) use a similar approach with a different production function taken from Zellner and Revankar (1969). Presenting estimates of structural efficiency from 28 individual dairy plants during the period 1964-73 (Sweden),

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[1]The industry production function is conceptually a frontier of potential attainment for given input combinations. The production function for any particular firm may conceptually be obtained from the industry function in terms of the firm's ability to implement optimal values of parameters in the industry. (Aigner and Chu, p.826)

[2]Aigner and Chu had only, as an objective, to derive a frontier production function. They did not try to measure technical efficiency.

Forsund and Hjalmarsson (p.303) show that the same output in different years could have been produced by 57-70% of the observed amounts of inputs used.[3]

From basically the same framework, Timmer (1971) introduced a variant in deriving a probabilistic frontier model. Since this mathematical programming method is thought to be sensitive to outliers, he proposed to drop the most efficient observations from the sample until estimated coefficients stabilised. Timmer used a Cobb-Douglas production function and aimed at estimating technical efficiency for U.S. agriculture from 1960 to 1967 across states. His results indicate that 75% of the states had measured efficiencies within 10% of the frontier. The least efficient state was less than 20% away from the frontier (pp.789-790).

The advantages of such a technique are the ability to characterize frontier technology in a simple mathematical form and to accomodate non-CRS technologies. The disadvantages result in being restricted to homogenous production functions and in the fact that the method imposes a limitation on the number of observations that can be technically efficient (only as many technically efficient observations as there are parameters to be estimated). Also, the estimated frontier is supported by a subset of the data and is therefore extremely sensitive to outliers. Timmer has suggested discarding a few observations until the estimation of the parameters has stabili-

[3]The estimate of structural efficiency is represented by the distance of the average plant to the frontier function for given output. It is a measure of the relative reduction in the amount of inputs needed to produce the observed average industry output with frontier function technology with the observed average factor proportions and size of plant (Forsund and Hjalmarsson, 1979, p.303).

zed. The estimates which this method produce have no statistical properties so no inferential results can be obtained. Finally, we cannot obtain a measure of allocative efficiency since the model is based on the estimation of a production function.

2.3 Deterministic statistical frontier model

Afriat (1972) was the first to introduce statistical analysis by making some assumptions about the distribution of the error structure. He estimated a Cobb-Douglas production function ($\ln y = \ln f(x) - u$) where the residual term ($u > 0$) was assumed to be independently and identically distributed (X was assumed to be exogenous). Afriat proposed a two-parameter beta distribution for u and estimated the model using the maximum likelihood method (MLE). With this technique, it is only possible to obtain a mean efficiency for the sample of firms, whereas the linear programming technique permitted a measure of efficiency for each firm. The estimated mean of u becomes the mean technical efficiency. When a specific distribution is assumed for u, the parameters of this distribution can be derived analytically from its higher moments and estimated consistently from the moments of the residuals. Using Aigner and Chu's statewide data on the U.S. primary metals industry, Greene (1980) estimated a translog cost function and its cost shares using annual time series data (1947-1971) for the U.S manufacturing sector. He used MLE and a Gamma density function. His results indicated a mean technical inefficiency of about 2.2% and no systematic allocative inefficiency (pp.110-111).

The disadvantages of this technique include the fact that different assumed distributions for u lead to different estimates and we have no «a priori» strong arguments for any particular distri-

bution. Furthermore, the range of the dependent variable depends on the parameters to be estimated, violating the regularity conditions for MLE[4]. The frontier is assumed to be deterministic, so the random shocks affecting the firms are influencing the measurement of efficiency. The advantages are that the estimates have statistical properties and are not strongly influenced by outliers. Furthermore, there are no limitations on the number of observations that can be efficient. We can use several functional forms to characterize the technologies. Also mean measures of technical and allocative efficiency can be obtained.

2.4 Stochastic statistical frontier model

The above frontiers are deterministic. The essential idea behind the stochastic frontier model is that the error term is composed of two parts: a symmetric component that permits random variation of the frontier across firms, and captures the effect of measurement error, other statistical noise, and random shocks outside the control of the firm; and a one-sided component which captures the effect of inefficiency relative to the stochastic frontier. This is represented by $y = f(x) - (u+w)$ where w is the symmetric component and u the one-sided component, $u > 0$. Even though the frontier is stochastic, the concept of technical efficiency is consistent with Farrell's

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[4]Greene (1980) has shown that the density of u must satisfy certain conditions for MLE to be consistent and asymptotically efficient. But further problems remain with his method since estimation of the model where the distribution of the error term is assumed to be gamma distributed are very difficult to implement (according to Greene). When the distribution of the disturbance term is assumed to be exponential or half-normal, Schmidt shows that the regulatory conditions are violated; specifically the condition concerning the range of the random variable being dependent on the parameters estimated (1976, p. 239).

definition of technical inefficiency as an equiproportionate overuse of all inputs. Allocative efficiency results in utilization of inputs in the wrong proportions with respect to a particular output. The residuals of the input demand functions derived from the first order conditions of cost minimization are interpreted as a measure of allocative inefficiency. Therefore, the various measures of efficiency presented earlier are still relevant in the context of a stochastic frontier production function even though the efficient isoquant (frontier) is stochastic in the sense that its placement is allowed to vary randomly across firms while a one-sided component captures randomness under the control of the firm (Schmidt and Lovell, 1979, pp. 344-345).

Schmidt and Lovell (1979) have estimated such a model for privately-owned steam-electric generating plants operating in the U.S.. They obtained a measure of mean technical inefficiency of 9.9% while allocative inefficiency was estimated at 8.1% (pp. 359-360). Stevenson (1980) estimated a translog cost function using privately-owned regulated electrical utilities. His results indicated a mean technical inefficiency of 14.86%. No allocative inefficiency was reported since he estimated a translog cost function without its cost shares (p.65).

Another stochastic frontier model is the corrected ordinary least squares approach (COLS). This model starts with the stochastic function specification presented earlier: $y = f(x) - (u+w)$ where w is assumed to have a symmetric distribution to capture the random effects of measurement error and random shocks. Technical efficiency relative to the stochastic frontier is captured by the one-sided

error component $-u$, $u > 0$. The estimation procedure requires obtaining residuals from an OLS estimate of the production or cost function. These residuals provide consistent estimates of the moments of the error distribution. This method requires an hypothesis about the distribution of the error terms as in the MLE estimation. Then, we can correct the estimated constant term. This estimation method[5] provides consistent estimates of all the parameters of the model.

The main advantages of the COLS estimate are that it is easy to use and provides consistent estimates of all the parameters of the stochastic model. The disadvantages include the fact that it is less efficient than MLE estimators and there is no guarantee that the estimates of the variances of u and w obtained from the moments will be non-negative. This would imply that some of the observations would be above the estimated frontier. A more serious weakness has to do with the fact that when using a model in which allocative efficiency is not assumed to be zero, the moments of the disturbance are intractable[6] and we cannot obtain consistent estimates of all the parameters. This limitation implies that the COLS method cannot be used when we want estimates of allocative as well as technical efficiency. Finally, this approach requires simple specifications like a Cobb-Douglas function in order to determine technical inefficiency from the distribution of the disturbance terms.

The main disadvantage of the stochastic frontier model with maximum likelihood estimation is that there is no good «a priori»

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[5]Schmidt and Lovell (1979) refer to it as the OLS/moment method.

[6]Schmidt and Lovell (1979, p. 357).

argument to select among possible specific distributions of the error terms. However, Aigner, Lovell and Schmidt have estimated a Cobb-Douglas production function for the 1957-58 data on the U.S. primary metals industry across 28 states using exponential as well as half-normal distribution of the disturbance terms. Their results indicate very close results for the estimated parameters of the production function and the distribution of the disturbances (1977, pp. 32-33). Furthermore, the choice of a functional form for the production function is somewhat limited since the production function must be homothetic.

The advantages of the latter approach include the fact that the presence of the symmetric component in the residual term solves the bounded-range problem encountered with some variants of the deterministic frontier model; therefore, the regularity conditions for MLE are respected. Technical and allocative efficiency can be obtained by estimating a system of equations. The estimates of allocative efficiency can be obtained on an observation by observation basis and averaged in order to measure the mean allocative efficiency over the sample. Moreover, Jondrow et al. (1982) have shown that we can decompose the residual components of the production function in its two portions. They derive the conditional density function which allows an estimation of technical inefficiency on an observation by observation basis. Furthermore, the introduction of a stochastic component in the model is certainly a step closer to reality. In a world of uncertainty, managers cannot be expected to control every aspect of the firm's environment (internal and external). Also, having to consider random shocks, statistical noise and measurement

errors as part of inefficiency was a weakness of the deterministic models that has been overcome with the stochastic frontier models. Compared to deterministic parametric frontier models, stochastic frontier models are not as sensitive to extreme outliers, and no limitation is imposed on the number of observations that can be efficient. Compared to the COLS models, more functional forms for the production function can be used to represent the underlying technology[7].

2.5 Non-frontier efficiency models

Lau and Yotopoulos (1971, 1973) developed a model to measure technical and allocative efficiencies. A sample of n firms is partitionned into two types (small vs large, public vs private, etc.). The prediction function is written:

$$Y_j = A_j\ f(x_i), \quad i=1,\ldots,n$$

where the terms $A_j > 0$ index technical efficiency with the two types of firms being equally technically efficient if, and only if, $A_1 = A_2$. The first order conditions for profit maximization are written $d\ A_j f(x_i)/d\ x_i = l_{ij}(w_{ij}/p_j)$. The terms $l_{ij} > 0$ index allocative efficiency and represent the ability of a type of firm to equate the value of an input's marginal product with its normalized prices. The two types of firms are equally price efficient if, and only if $l_{1j} = l_{2j}$, and if they are absolutely price efficient, then $l_{ij}=1$. Finally, the two types of firms are equally economically efficient if, and only if, their respective profit functions coincide. From a specified functionnal form, and the derived first order conditions for profit

[7] Kopp and Smith estimated a stochastic frontier model using a CES, CD and translog production function (1980).

maximization, we can test the following hypotheses: equal technical efficiency, equal price efficiency, equal economic efficiency, and absolute price efficiency for each group of firm (for example, publicly owned vs privately owned firms).

The disadvantage of this model is that it cannot be extended to investigate efficiency on a firm-by-firm basis. Also, the functionnal form chosen for the production function must be sufficiently tractable to permit derivation of the associated profit function. Furthermore, no absolute measure of technical efficiency can be computed since no efficiency frontier is estimated. Yotopoulos and Lau (1973) estimated their model using data from the small and large Indian farms between 1955 and 1957. Their results indicate that small farms are more economically efficient. The relative economic efficiency of small farms is not due to superior price efficiency (both are found to be price efficient), but they have established the superior technical efficiency of the small farms (p. 222)

A second model, developed by Toda (1976), can be used to investigate allocative efficiency. He assumes that the firm is technically efficient, and its cost function is a generalized Leontief function as follows:

$$C = A_{11} p_1 + 2 A_{12} p_1^{1/2} p_2^{1/2} + A_{22} p_2$$

where

C - unit cost minimum at the given output level

p_1 - price of capital as the shadow price

p_2 - wage rate as the shadow price

$A_{12} \geq 0$

Since the partial derivatives of the cost function with respect to

the factor prices must equal the quantity of that factor,

$$k/y = A_{11} + A_{12}\ (p_1/p_2)^{-1/2}$$

$$l/y = A_{22} + A_{12}\ (p_1/p_2)^{1/2}$$

where

k/y - capital-output ratio

l/y - labor-output ratio

Toda introduces an hypothesis that the observed price ratio differs from the shadow price ratio by a fixed proportion a,

$$p_1/p_2 = a\ w_1/w_2$$

where

w_1 - observed price of capital

w_2 - observed wage rate

$a > 0$

Under this hypothesis the demand functions, k/y and l/y, are expressed with the observed prices as independent variables

$$k/y = A_{11} + A_{12}\ (a\ w_1/w_2)^{-1/2}$$

$$l/y = A_{22} + A_{12}\ (a\ w_1/w_2)^{1/2}$$

Substituting the observed demand functions in the cost function

$$C = A_{11}\ w_1 + (a^{-1/2} + a^{1/2})\ A_{12}\ w_1^{1/2}\ w_2^{1/2} + A_{22}\ w_2$$

which is different from the minimum cost function

$$C^* = A_{11}\ w_1 + 2\ A_{12}\ w_1^{1/2}\ w_2^{1/2} + A_{22}\ w_2$$

When the coefficient $a = 1$, $C^* = C$. At this point the observed price ratio coincides with the shadow price ratio. Toda suggests estimating a system of equations. After concerting the system of equations (demand functions) into an equivalent system shown as:

$$y = A_{12}\ (a^{1/2} - a^{-1/2})\ d + A_{12}\ a^{-1/2}\ w + A_{11}\ c_1 + A_{22}\ c_2$$

where

$y = (k/y, l/y)'$

$w = ((w_1/w_2)^{1/2})'$

$d = (0, (w_1, w_2)^{1/2})'$; the dummy price variable,

$c_1 = (1, 0)'$; the intercept,

$c_2 = (0, 1)'$; the intercept,

If the observed prices equal the shadow prices (a = 1), the coefficient of the d variable will vanish so that the symmetry restriction across equations will be imposed on the coefficients of the price variables. Toda estimates the last system of equations with and without the d variable. The significance of the price disparity is tested by the extent to which the sum of squares of residuals diminishes by adding the d variable (pp. 259-262).

This model has been estimated by Toda (1976) for the Soviet manufacturing industries. His results indicate that for five industries one cannot reject the null hypothesis that the factor price ratio equals the marginal productivity ratio. Significant results are obtained only for three industries (p. 263).

The advantage of this method is that it can be used with more flexible forms. The disadvantages are that the measures of allocative inefficiency are not firm specific, and the parameter a measures only the systematic portion of allocative inefficiency (Forsund et al., 1980, p. 19)[8].

2.6 Total factor productivity (TFP)

Caves and Christensen (1980) have used the total factor productivity approach to compare relative efficiencies. They claim that TFP

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[8]According to Forsund et al. (1980, p. 19), technical inefficiency might be introduced in this model by adding one-sided disturbances to the input demand function and the cost function.

is the single best measure of productive efficiency (1980, pp.960). TFP is defined as the real output per unit of real resources used. The computation of TFP requires the estimation of the following equation:

$$\ln(TFP_k/TFP_l) = \Sigma\, n_i\, (R_{ik} + R_{il})/2 * \ln\, (Y_{ik}/Y_{il}) -$$
$$\Sigma\, n_i\, (CS_{ik} + CS_{il})/2 * \ln\, (X_{ik}/X_{ik})$$

where

. k, l are adjacent time periods in the case of cross-sectional comparisons

. Y's are output indexes

. R's " " revenu shares

. CS's " input cost shares

. X's " " indexes

. i denote the individual output, input

According to Caves and Christensen, this equation is the exact index procedure which corresponds to a homogeneous translog production function (p. 963). The estimation of such model for the Canadian railroad industry indicated that between 1956 and 1965 the federally owned Canadian National railroad productivity increased between 80% and 90% as rapidly as that of the privately owned Canadian Pacific railroad[9]. From 1964 to 1968 the relative productivity increases were reversed (p. 967).

The advantage of this model is that it allows the use of a more involved functionnal form (translog). The main disadvantage is the fact that TFP does not discriminate between types of inefficiencies. It does not provide an estimate of efficiency with respect to a

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[9] The CN is owned by the Federal government while the CP is privately owned.

frontier. In the measurement of TFP are incorporated returns to scale, price effect, regulation effect, inefficiencies, ect., with no way to separate them. Finally, it does not account for the random variations outside the control of the firm, measurement error, or other statistical noise that may affect the estimates. Finally, the measurement of increases in comparative efficiency will be affected by the starting point; if a firm is poorly managed and recoups some of its inefficiency over the years, it would perform well compared to an initially more efficient firm.

2.7 Dummy variable model

Comparative efficiencies across various types of organizations have also been studied using average production[10], cost and profit functions estimated by OLS techniques. In order to account for organizationnal differences a dummy variable is included in the model to be estimated. Dilorenzo and Robinson (1982), Meyer (1975) and Pescatrice and Trapani (1980) used such a methodology. For example, Pescatrice and Trapani estimate a translog cost function assuming that the firm minimizes its cost of production. The model to be estimated is a system of equations composed of the cost function and its cost shares. After pooling the data for public and private firms, a binary variable reflecting the mode of ownership is introduced in the model. Efficiency is not estimated directly, but the comparison between organizations provides some measure of relative efficiency.

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[10]Forsund et al. (1980, p20) state that the term frontier is associated with maximal possible output while the average function is associated with mean output. The notion of an average function would perhaps be more meaningful in a random coefficients model. An average function can then be defined as the function obtained when the random coefficients obtain their expected values .

(Estimates of relative efficiency obtained from the binary variable model will be presented in the next section).

The main advantage of this approach is its simplicity since it only requires estimation of a simple function using OLS. The disadvantages are numerous. First, the estimation of a production technology using a cost function and duality theory requires the firm to be efficient in the first place. This implies that the firm must be producing on its frontier and be allocatively efficient. Furthermore, the binary variable measures a combination of random shocks, technical and allocative efficiencies. Finally, it uses the concept of mean output which does not allow an estimate of an efficient frontier, and therefore, no absolute measure of efficiency can be computed.

3- Review of the literature on estimates of relative efficiencies of private and public electric utilities[11].

Many empirical studies have been done with the electric utilities, covering a wide range of topics including measurement of economies of scale, elasticities of substitution and technical change[12]. Few of them address the issue of efficiency comparisons across various types of organizationnal structure. The following section reviews these contributions with respect to their methodology, results, and validity.

Meyer (1975) is concerned about the influence of ownership on the adoption of new innovations and other costs of providing services. To

[11]As far as we can tell, there is no study dealing with consumer cooperative electrical utilities and the concept of efficiency comparison.

[12]See Cowing and Smith (1978) for a survey of that literature.

test his hypotheses he makes use of the duality relationship between technology sets and cost functions. He used a dummy variable approach which pooled both private and public firms; and used a Chow test for the equality of all the coefficients estimated for the private and public firms. The model estimated is as follows:

Cost = f (dummy, gen, gen^2, gen^3)

where

Cost - total cost of production,

dummy - dummy variable to account for ownership form,

gen - net generation in 1000's kwh as a measure of output.

Meyer found significant differences in the cost function between private and public utilities in each year (1967, 1968, 1969), with public firms having lower costs (no magnitude of the difference was given). The Chow test indicated that the coefficients of the cost functions were not the same (p. 393).

Even though Meyer concluded that ownership seemed to matter, he recognized that sources of the cost difference were not identified. No attempt was made to control for such important factors as prices of inputs, technology, regulatory influences and the objective functions of each ownership structure.[13]

Sowell (1978) assessed the relative efficiency of private and public enterprises. He hypothezised that neither private nor public firms are likely to satisfy the prerequisites for efficient allocation; based on non transferability of ownership, an active zero

[13]However, Meyer recognizes that comparison of cost alone cannot determine whether firms are using the least cost technology available. He noted that technological possibilities, prices of inputs as well as objective function have to be accounted for (p. 392).

profit constraint, and low opportunity costs associated with non pecuniary income, he predicted that the effects on resource misallocation should be more pronounced for publicly owned firm. Recognizing that production may be characterized by: (1) increasing returns to scale, (2) limited ex-post substitution, (3) non-neutral technical change, Sowell retained a generalized Leontief production function. Regulatory constraint and price subsidization were specified in his models estimated for private and public plants respectively. Input demand functions were derived and estimated. His model tested for fixed input coefficients, duality between cost and production which implies consistency with cost minimization, substitutability between inputs, cost differences between ownership forms, and a test for the possibility of difference between market and reported prices using Toda's methodology. If duality between cost and production holds exactly for each form of ownership, Sowell states that cost differences arising from different technologies may be ruled out; when both forms show cost minimizing behavior, cost differences can be imputed to input prices and relative efficiency of ownership structures (p .41). But if both are cost minimizing, cost differences can be imputed to different technologies and/or different prices. Furthermore, if duality holds, the plants will exhibit cost minimizing behavior, allocative inefficiency accounted by differences between market prices and reported prices is ruled out. His models were estimated on annual observations of steam electric generating plants placed in operations in the Southern United States between 1950 and 1970. The data on costs for the plants covered five years from 1968 to 1972. The sample included 30 private and 14 publicly owned plants.

Sowells' results indicated that the regulatory constraint for the private firm was not binding. Furthermore, the underlying duality between cost and production functions were satisfied, implying that cost minimizing input combinations were estimated. However, his results indicated allocative inefficiency in private firms with respect to capital and fuel. Those results are in contradiction with the implication of cost minimization which requires the firm to be both technically and allocatively efficient (Forsund et al., 1980, p. 7). Using the sample means for the price variables and the level of output, the average cost and the marginal cost were .02$/kwh and .0175$/kwh, respectively. The constrained estimates were not fully consistent with cost minimization for publicly owned firms. The subsidization of input prices did not significantly influence the firm. Again using the sample means for input prices and the level of output, the estimated average cost and marginal cost were .055$/kwh and .069$/kwh, respectively. Based on the comparisons of average and marginal costs, Sowell concluded that the private firms were more efficient than the publicly owned firms. His input demand equations suggested that both ownership forms showed allocative inefficiency.

Sowells' results are contradictory since he claims that duality between cost and production exists even though allocative inefficiency is reported. Furthermore, even if duality was confirmed, cost difference could still be attributed to technology differences as well as price differences. Sowell assumed that technology of public and private firms were similar since they respect the duality condition, and he drew his conclusion on the basis of AC and MC

comparison after controlling for price differences.

Pescatrice and Trapani (1980) sought to determine whether there is a significant cost difference arising from alternative forms of ownership. Their methodology required the derivation of objective functions for both public and private firms. The regulated private firm is perceived as minimizing its internal cost of producing a given level of output, while the objective of the public firm is revenue or output maximization under zero profit constraint. Using a translog production function and cost minimization, they estimate a cost function and the cost share equations for a sample of 33 private and 23 public firms. A dummy variable accounts for the type of ownership. Output, factor prices and technology[14] are controlled. A pooled sample is estimated assuming the regulatory effect on private firms is zero. Their results suggest that public firms have 24-33% lower per unit costs than private firms. They attribute these differences to the behavioral objectives of public and private firms, whereby public firms seek to minimize true cost while private do not because of the effective rate of regulation of private firms[15] (p. 275).

Dilorenzo and Robinson (1982) hypothesize that public firms operating in a competitive environment act in ways similar to their private counterparts. Political competition is thought to impose the same cost-minimizing pressures on public managers as does economic competition on managers of private firms. They predict no difference

[14]Pescatrice and Trapani consider only electric utilities using fossil-fuel (coal, gas, oil) steam-electric operations to generate electricity. Furthermore, vintages are also accounted for.

[15]The Averch-Johnson effect could not be confirmed (p. 271).

in production efficiency between ownership structure. Their estimation is based on the following short run cost function:

$$TC = a_0 + a_1 Gen_i + a_2 Fuel_i + a_3 Cap_i + e_i$$

where

TC = total annual steam production expenses,

Gen. = steam generation in kwh,

Fuel = weighted average fuel cost per billions of kwh,

Cap = total generating capacity of steam plant,

Dilorenzo and Robinson controlled for technology by using firms for which steam electricity generation accounted for a great majority of total net generation. They retained those firms with average net generation for the sample period between .5 and 4 billions kwh. Finally, only those utilities which provided service to every customer type were included[16]. To test for efficiency differences, they pooled the sample of public and private firms, and a dummy variable was included in the above cost function. The results indicated that privately owned electric utilities were significantly less cost efficient than public electric utilities (p. 120). They did not report the magnitude of the difference. Dilorenzo and Robinson did not explain their results other than by saying that rate regulation leads to overutilization of capital while public firms could be enhanced toward more efficiency when they are operating in a competitive environnement (p. 112).

4- Conclusion

This chapter has reviewed several models that could be used to

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[16]Their data set included 18 public firms and 23 private firms for 122 observations over the years 1970-1972.

test for efficiency. The selection of the proper model has to consider what each of those is capable of doing with regard to the objective that is pursued. The stochastic frontier model offers several advantages over other models.

If we compare stochastic frontier models to deterministic parametric and non-parametric models, the former have the advantages of allowing an unlimited number of observations to be technically efficient[17], and it is not sensitive to outliers. Random shocks, statistical noise, and measurement errors are not confused with measurement of technical efficiency. The stochastic models permit measurement of technical and allocative efficiencies separately and these estimates have testable, statistical properties. Finally, deterministic parametric frontiers represent the concept of best practice technology while stochastic frontier models represent the most efficient technology. The best practice technology is likely to overestimate technical inefficiency. They can estimate technical efficiency observation by observation.

When comparing the stochastic frontier models to the deterministic statistical models, the stochastic frontier models shows some advantages while deterministic statistical model shows a bounded range problem when using such distributions as exponential and half-normal disturbance terms. (Greene has shown that it was possible to solve that problem by using a Gamma density function, but the model becomes very difficult to estimate). The deterministic statis-

[17]The stochastic frontier model and the deterministic statistical model allow each firm to be efficient with respect to its own frontier while the deterministic parametric model is based on the concept of best practice technology one can observe.

tical model considers random shocks, measurement error and statistical noise as part of technical efficiency while the stochastic frontier model separates those from technical efficiency. Both models have no «a priori» good arguments to select a distribution for the disturbance term. Furthermore, both models can estimate technical efficiency observation by observation when technical and allocative efficiency are estimated simultaneously. Finally, they are both limited in the choice of functional form: the production function must be homothetic.

The advantages of stochastic frontier model over non-frontier models are due to the fact that inefficiency parameters estimated from non-frontier models are not firm specific, even for allocative efficiency measurement, and measure only the systematic portion of allocative inefficiency (Forsund et al., 1980, p. 19). It is argued by Forsund et al. that technical inefficiency can be introduced by adding one-sided disturbances to the system of input demand equations, but this procedure makes the model stochastic.

Finally, when compared to the dummy variable model, the stochastic frontier model shows several advantages as well. First, the concept of an average function, which is used in the dummy variable model, does not represent the most efficient technology. The dummy variable measures a combination of random shocks, technical, and allocative efficiency (when the cost function is estimated) and is not capable of discriminating between them. No absolute measure of efficiency (technical and allocative) can be obtained from such a model. Furthermore, the estimation of a dummy variable model requires that we pool data for different ownership structures together in

order to estimate the coefficient of the binary dummy variable. This procedure can cause biases when technologies are different, which may be the case for public and private utilities.

Several papers dealing with the comparison of efficiencies by ownership types have been reviewed. All the papers reviewed show methodological limitations. Three of those used the dummy variable approach and estimated that public utilities were more efficient than private utilities. Pescatrice and Trapani estimated the cost difference between private and public to be 24-33% per unit of output in favor of public utilities. All three papers estimated cost functions, used pooled public and private utilities, and assumed that technologies were the same (no dummy variables were introduced to account for possible different coefficients in the cost functions). From those studies we have an indication that public utilities are more efficient. We do not know if one or both ownership structures are efficient, and we have no indication as to which type of inefficiency is more important.

Sowell's procedure is more appropriate since he used an approach developed by Toda in estimating a generalized Leontief average cost function and its input demand equations. He estimated different models for each ownership structures and controlled for regulation as well as capital subsidization for public firms. He used average output and input prices to calculate AC and MC for each ownership structure. Private utilities showed lower AC and MC than public utilities. Furthermore, his estimates allowed him to conclude that both private and public utilities were allocatively inefficient. Sowell did not provide any separate estimates of technical and

allocative efficiency. However, his results are contradictory since he claims that private and public plants respect duality conditions, and at the same time they show allocative inefficiency. His conclusion on ownership efficiency is based on a comparison of AC and MC, but technology of public and private plants are not controlled for.

The review of these tests of efficiency and ownership structure shows that much remains to be done. The next chapter presents an appropriate methodology and the models to be estimated in order to answer some of the questions regarding the technical and allocative efficiencies of various ownership structures.

FOURTH CHAPTER

TECHNOLOGY AND MODELS TO BE ESTIMATED

1- Introduction

To characterize technology, the main features of interest are: substitution among factors, returns to scale and homotheticity, and the nature of technical change. Several functional forms are available to capture the characteristics of the technology; the most frequently used are : (1) Cobb-Douglas, (2) CES, and (3) Translog. Other functional forms can be found in the literature: (1) Zellner-Revankar, (2) Nerlove-Ringstad, (3) Fixed coefficient, and (4) Generalized Leontief. Only the first three models will be discussed with respect to their ability to capture the features of technology of electricity generation. Those three are better known and most widely used.

Section two discusses the basic characteristics of the technology underlying electricity generation. Section three discusses the various restrictions that functional forms (C-D, CES, translog) place on the underlying technology. The fourth section discusses the choice of the proper functional form with respect to the objectives of the research, the possible distortions due to their built-in restrictions, and the ability to capture technololgy. Finally, in the fifth section, the theoretical model to test for efficiency differences is presented. This section includes the functional form of the production function, the justification of the objective function for each type of firms, a derivation of the system of equations that will be estimated, and the relevant likelihood function.

2- Technology of electricity generation

2.1 Basic characteristics

Technology of electricity generation can be characterized at three different levels: boiler-turbine-generator (BTG), plant, and firm. It can be characterized differently for estimation at each of those levels of aggregation. Kopp and Smith (1978, p. 1050) argue that returns to scale measured at the firm level will depend not only on the returns to scale of the plants but also on their respective rates of utilization. The characteristics of technology will be influenced by the aggregation process. Fischer, et al. (1969) also argue that differences in the type of plants and their pattern of use across firms can seriously affect the relationship between characteristics attributed to the technology from aggregate firm estimates.

A second basic characteristic to consider when estimating technology is to distinguish base load from peak load plants. Electric utilities have to supply all demands for electricity. Since demand fluctuates over time, some plants are used only to satisfy peak demand. Therefore, it would not be appropriate to mix plants aimed at different uses, even if they embody the same technologies. According to Kopp and Smith (1980), either some adjustment for capacity utilization or selective sampling of plants will be necessary to assure comparability in the association between the flows of inputs and output produced for all plants in the sample. Since it is difficult to develop accurate measures of input usage and to correct for peak versus base load use, selective sampling technique is more

appropriate. It is argued that plants of recent vintages are likely to be base load plants[1].

The third basic characteristic refers to whether one seeks to estimate ex-ante or ex-post technology. Ex-ante refers to technology at the blueprint stage. The entrepreneur selects a configuration of generating equipment from these blueprints, perhaps on the basis of input prices. Ex-post refers to the technology associated with a specific blueprint that has been put in place in the plant. Features of the technology, and certainly efficiencies may appear different if we are using ex-ante or ex-post data to estimate the production function. Once a plant's design characteristics are fixed in terms of a specific configuration of capital equipment, technology is ex-post and the scope for substitution will be substantially reduced. In this research, models with assumed ex ante and ex post technologies are estimated separately.[2]

2.2 Factor substitution

The use of ex-ante rather than ex-post technology models as well as the use of plant rather than firm will affect the estimates of factor substitution elasticity among inputs. Ex-post technology should show less substitutability among inputs than estimates

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[1]It makes sense to assume that new plants will be of base load characteristics since technical change is mostly embodied in electricity generation. Firms will have incentives to use new plants (and most efficient) if they behave as cost minimizers. Older plants (less efficient ones) would be kept for peak load purposes. Of course, the least cost operation requires the use of appropriate plants. This plant mix problem is not considered in this research.

[2]As will be described in chapter 5, our data set comprises information with respect to the first 5 years of operation of each plant. Therefore, it is likely that we will not have a clear ex ante or ex post technology, but a mixture of both.

using ex-ante technologies. For example, Cowing and Smith's survey article (1978,p.180) shows that elasticities of substitution estimated using ex-post technology models are less than those for ex-ante models, though still significantly different from zero in both cases.[3] The estimation of various pair elasticities ranges from .1 to .75.

2.3 Technological change

Technical change characterizes the process by which a technology changes over time. Generally it involves a description of the mechanism by which these changes are introduced into the production activities and an indication of their effect on optimal factor input use.

Embodied technical change has been shown to be appropriate for the technology of electricity generation (Cowing and Smith, 1978, p. 179). It specifies that new capital equipment reflects the changes which occur in technology. In this case, different technologies are distinguished according to the time periods, or vintages, in which the capital equipment was built. Technological changes have also been shown to be labor and fuel saving, that is to say non-neutral (Cowing and Smith, 1979, p. 179).

2.4 Scale effects

The scale effects refer to whether technology is homogenous or homothetic. Most empirical studies have assumed electricity generation technology to be homothetic (MRTS is constant along a factor ray) (Cowing and Smith, 1978, p. 178). However, Christensen

[3]All the studies reviewed by Cowing and Smith except two (Nerlove, Christensen and Greene) are using data evaluated at the plant level.

and Greene (1976, p. 665), estimate input share equations derived from a translog cost function, arguing that technology is non-homothetic.

Technology also has to be characterized with respect to returns to scale. According to Cowing and Smith (1978, p. 178) there appears to be significant scale economies in steam generation between small and intermediate-size BTG units.

3- Functional forms[4]

3.1 Cobb-Douglas

The Cobb-Douglas production function is represented as follows :

$$(3.1)\ Y = A\, K^a\, L^b\, F^c$$

The Cobb-Douglas representation imposes the following restrictions on the production technology :

(a) homogeneity of degree $r=a+b+c$; and homotheticity

(b) elasticity of substitution = 1; implying that factor shares are independent of their prices.

(c) weak separability between inputs (the MRTS between any input pair is independent from the level of any other input)

Weak separability has the unrealistic implication that changes in relative prices of variable inputs will induce changes in the demand for those inputs which are independent of the level of fixed inputs.

In addition, technological changes can be expressed in terms of variations in the parameters of the production function over time. Variation in the intercept parameter A represents neutral technological change. A change in the intercept parameter represents a

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[4]This section draws from Brown (1966), and from Intriligator (1978).

disembodied technological change and can be depicted as a shift of the entire production function. It does not affect the MRTS between inputs. A non-neutral technological change is depicted by a variation in the ratio of the two elasticities of production; for example, a change in b relative to a or c. This alters the MRTS between inputs. Factor saving or factor using technical changes are indicated by the direction of change of these ratios.

3.2 Constant Elasticity of Substitution (CES)

The CES production function was developed in response to the restrictive characteristics of the Cobb-Douglas production function. It does not impose unitary elasticity of substitution among inputs, although it requires that elasticity be constant and independent of the level of factors of production used. It is represented as follows:

(3.2) $Y = A \quad a K^{-t} + b L^{-t} + c F^{-t} \; {}^{-r/t}$

where A is a neutral parameter, t is a substitution parameter, a, b, c are share parameters, and r represents the degree of homogeneity of the function (i.e. the degree of returns to scale[5]). Its characteristics are:

(a) homogeneity = r; the CES is homogeneous of degree r in the input levels.

(b) elasticity of substitution, $s = 1/(1+t)$

(c) strong separability

In the multi-input case s is identical for all input pairs.

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[5]The CES production function was derived independently by two groups, Arrow et al. (1961) and Brown et al. (1963). The second derivation is more general since it permits any degree of returns to scale as opposed to the first presentation where constant returns to scale is assumed.

Thus, although the CES function allows for elasticities of substitution different from one or zero, it does present the inconvenience of imposing equal substitution possibilities among all input pairs.

Disembodied technological change can be captured through parameter A and is classified as neutral technical change. Another parameter change which does not affect the MRTS between inputs is r, the parameter that captures the degree of returns to scale. Non-neutral technical change will be associated with share parameters a, b, c as well as with s, the elasticity of substitution.

3.3 Transcendental logarithmic (Translog)

The functional forms above imposed severe restrictions on the nature of production technology. In particular, restrictions regarding the elasticities of substitution and weak separability may be unrealistic and may induce serious specification errors in empirical analyses.

The development of more flexible forms provide appropriate functions to measure characteristics of technology. Flexible forms provide second order approximations to arbitrary functional forms. A functional form is flexible if the parameters of such a function may be chosen such that the value of the function and its first and second derivatives coincide with the value and first and second derivatives of any arbitrary function. Since the elasticities of substitution and separability conditions depend upon these values, a flexible form can accurately represent the elasticities of substitution and will be free of any separability restrictions. The translog is the most popular of these flexible forms. It reduces to multi-input Cobb-Douglas and a CES as special cases. It can be written as :

(3.3) $\ln Y = \ln a_0 + a_a \ln A + \Sigma^{n}{}_{i}\, a_i \ln x_i + 1/2\, b_{aa}(\ln A)^2 +$

$1/2 \Sigma^{n}{}_{i} \Sigma^{n}{}_{j}\, b_{ij} \ln x_i \ln x_j + \Sigma^{n}{}_{i}\, b_{iA} \ln x_i \ln A$

where Y - output

x_i- inputs

A - technology index

This function is in general non-homothetic but it includes homogeneity of degree one as a special case. When we assume homotheticity, the restrictions imposed on the translog correspond to homogeneity of degree one. Furthermore, the assumption of Hicks-neutral technical change is usually made. Therefore, with homotheticity and Hicks neutrality, the translog production function is:

(3.4) $\ln Y = \ln A + \ln a_0 + \Sigma_{i} a_i \ln x_i + 1/2 \Sigma_{i} \Sigma_{j} b_{ij} \ln x_i \ln x_j$

The factor shares are represented as follows :

(3.5) $S_1 = a_1 + b_{11} \ln x_1 + b_{12} \ln x_2 + b_{13} \ln x_3$

The factor shares are dependent on the input levels. Therefore, this function is non-homothetic and non-separable unless restrictions are imposed on the parameters.

The Allen partial elasticities of substitution for the three input case are:

(3.6) $s = [G_{ij}] / [G]$

where G is the determinant of the input share equations and G_{ij} is the cofactor G_{ij} in G. The estimated AES can be computed for each observation and input pair.

Finally, the translog is well suited to test if technical change is disembodied and/or embodied.

4- Selection of proper functional form

The selection of a functional form requires that we consider

the following elements: (1) objectives of the research (not all estimated functional forms provide the same information), (2) critical distortions in the estimated results caused by built-in restrictions in functional forms, and (3) the capacity of capturing critical characteristics of the technology.

In this research we are not directly interested in estimating the various characteristics of technology of electricity generation. The critical point is that the functional form does not distort estimates of inefficiency. Since the information required to test for efficiency differences across ownership structures will be provided by the disturbance terms appended to each model, all the above functional forms will provide the necessary information.

Each model presented in section 3 has advantages and disadvantages. The translog production function offers the most flexibility in capturing the characteristics of technology. However, the use of stochastic frontier model requires homothetic production functions in order to discriminate between the types of inefficiencies (Greene, 1980, p. 103). For the translog, this means imposing homogeneity of degree one. However, the estimation of a translog production function model along with its factor shares, is a considerably more difficult task than estimating other functional forms. It takes up a lot of degrees of freedom and requires imposing restrictions across equations. CES functional form allows varying rates of factor substitution, though substitution will be equal for each pair of inputs. It also allows varying returns to scale. However the CES production function is difficult to estimate since it cannot be linearized with

respect to its parameters. It has been shown to be difficult to fit to most data sets (Brown, 1966, p. 61). For the Cobb-Douglas form, factor substitution elasticities are constrained to be equal to one, while returns to scale are unconstrained. Technical change can be incorporated as embodied or disembodied change. Of all the functional forms Cobb-Douglas is the simplest to estimate.

The distortion of efficiency measurements caused by various production function models has been analyzed by Kopp and Smith (1980, p. 1057). They compare functional forms (C-D, CES, translog) with various frontier estimators. Their results[6] are shown in table 1:

Table 1
Estimates of technical efficiency and characteristics of technology using various functional forms

	vintage[7]	type of functional forms		
		C-D	CES	Translog
Technical inefficiency	1	.828	.828	.846
	2	.950	.952	.954
Returns to scale	1	1.003	1.002	IB
	2	1.054	1.005	1.244
Elasticities of substitution	1	1.0	.95	IB
	2	1.0	.867	.705

IB means ill-behaved

The measurements of technical inefficiency estimated from each

[6]Only the results with respect to stochastic frontier estimators are presented.

[7]Vintage refers to different technologies that are distinguished according to different time periods in which the capital equipment was built. Kopp and Smith pooled all steam electrical plants built between 1961 and 1965 in the first vintage, while plants built between 1966 and 1969 were grouped in the second vintage.

functional form are very similar[8]. These results are important since they seem to indicate that the selection of a functional form will not affect the measure of technical inefficiency. The Cobb-Douglas would impose a given shape upon the isoquant, since factor substitution is equal to one. From what we know about the technology, elasticity of substitution is less than one. To assume that $s = 1$ would flatten the frontier isoquant and impose an unrealistic assumption on the model. Therefore, it would likely result in a larger error term representing allocative inefficiency. If we assume that all organizational forms have similar elasticities of substitution among input pairs, the bias introduced by the unrealistic assumption of substitution elasticities equal to one would not likely differ across ownership types[9].

From the previous section we know that empirical studies show electricity generation technology to exhibit mildly increasing returns to scale, substitution among factors less than one for ex-ante technology; and, finally, embodied technological change, which is best captured by vintages and capital-using models.

Even though Cobb-Douglas is a more restricted form than the

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[8]Kopp and Smith did not obtain estimates of allocative inefficiency since they used only a production function.

[9]However, Sowell (1978, p. 89) states that: the general pattern of Allen elasticities of substitution are not similar for public and private plants. Private plants exhibit strong capital-labor and fuel-labor substitution and virtually zero fuel-capital substitution. Public plants display strong labor-fuel substitution and limited fuel-capital substitution. Labor and capital are complements in publicly owned production .

others[10], it is an appropriate model considering the objectives of the research and the limited distortions it places on technical inefficiency measurements. The Cobb-Douglas production function will be selected because: (1) it provides us with all the required information to compare technical and allocative efficiencies among various organizational forms, (2) it does not introduce biases in the measurement of technical inefficiency, (3) it captures several important characteristics of technology underlying electricity generation, (4) it is easier to estimate than any other functional form, (5) it has been used with stochastic frontier estimation, providing us with a benchmark to compare our results; and (6) it is not evident that placing unrealistic restrictions on substitution elasticities will affect the relative measures of allocative inefficiency across ownership types.

5- Model to be estimated

5.1 Introduction

The complete model requires that we select a proper objective function to characterize the behavior of the firms. This is an important task since measurement of inefficiency depends on a standard of comparison which is derived from our behavioral hypotheses with regard to each type of ownership structure. We also have to derive the system of equations from the selected production function and the objective function. We have established that a stochastic frontier model best meets the objectives of this research. However,

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[10] We have to remember that frontier estimator requires homotheticity, and because of that restriction translog is assumed to be CRTS. Furthermore, a translog functional form is more difficult to estimate because of restrictions across equations.

the use of such a model requires some hypotheses about the error structure. Such hypotheses will be discussed and a derivation of the relevant likelihood function will be presented. A discussion of the estimation procedure will complete this section.

5.2 Objective function for each type of ownership

In electric utilities, the literature strongly suggests that output is exogenous to the firm. Nerlove was one of the first to assume that electric utilities would, therefore, behave as cost minimizers. He argued that[11]:

1. Power cannot be stored in large quantities and must be supplied on demand.
2. Revenues from the sale of power by private companies depend primarily on rates set by utility commissions and other regulatory bodies.
3. Much of the fuel used in power production is purchased under long-term contracts at set prices. The level of prices is determined in competition with other uses.
4. The industry is heavily unionized, and wage rates are also set by contracts that extend over a long period of time. Over long periods, wages appear to be determined competitively.
5. The capital market in which utilities seek funds for expansion is highly competitive and the rates at which individual utilities can borrow are little affected by individual actions over a wide range.

From these characteristics Nerlove draws two conclusions. First, it is possible to regard output of a firm and the prices it pays for

[11]Nerlove (1963, p. 168)

inputs as exogenous. Second, the problem of the individual firm in the industry would appear to be that of minimizing the total costs of production of a given output, subject to a production function and the prices it must pay for factors of production. Most economists have followed Nerlove's cost minimization assumption on the grounds that output is exogenous to the plant. The arguments presented to justify cost minimization for private utilities can apply to public as well as cooperative utilities. Power cannot be stored for them any more than for private plants. Prices of fuel and labor will certainly be determined with long term contracts as for the private plants, and will be determined competitively over long periods. The price of capital for public and cooperative firms is not a market price. Both are receiving subsidies from the government. However, the price of capital is still exogenous to the firm since it is determined by governmental policy. Only the rate of return condition is not met. This is irrelevant in this context since output is exogenous to the plants. Even if public and cooperative firms aimed at maximizing profit, the optimum solution would be equivalent to that of cost minimization when output is exogenous[12].

5.3 Derivation of models to be estimated

Several models can be derived and estimated to obtain the information required to test our hypothesis with respect to efficiencies of ownership structure. One could directly estimate a production or a cost function. The former is inappropriate since the estimates

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[12]Pescatrice and Trapani hypothesize that public utilities will have an objective of revenue or output maximization rather than profit maximization. Furthermore they present some evidence that public utilities behave as cost minimizers (1980, p.271).

would be inconsistent. This is because output is exogenous and inputs are related to one another through cost minimization. Such a model would show severe multicolinearity and has to be rejected. The estimation of the cost function can be appropriate under certain circumstances. Since the right-handside variables of the cost function are exogenous, it can be estimated without worrying about complications due to simultaneity. However, the cost function model does not provide all the information needed to distinguish technical and allocative inefficiencies. The moments of the disturbance characterizing the stochastic cost function (to be described later) are intractable, and we cannot manipulate them to obtain consistent estimates of the parameters of the distribution of the disturbance. It means that we cannot distinguish between technical and allocative inefficiencies on the basis of a cost function alone[13]. However, if we make the hypothesis that plants are allocatively efficient, a cost function is sufficient to measure technical efficiency. In order to obtain consistent estimates of all the parameters, we can estimate a system composed of a production function and the first order cost minimizing conditions; or alternatively, estimate the set of derived input demand equations. According to Schmidt and Lovell (1979, p. 357) the simpler choice is to apply a Maximum Likelihood Estimator (MLE) to the production function and the first order conditions. Assuming a C-D technology, the Lagrangian and first order conditions are:

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[13]Schmidt and Lovell (1979, p.357)

(5.1) $$Z = P_k K + P_l L + P_f F + g\,Y - A\,K^a\,L^b\,F^c$$

$$P_k - A\,a\,K^{a-1}\,L^b\,F^c = 0$$

$$P_l - A\,b\,K^a\,L^{b-1}\,F^c = 0$$

$$P_f - A\,c\,K^a\,L^b\,F^{c-1} = 0$$

$$Y - A\,K^a\,L^b\,F^c = 0$$

Using price of labor as the numeraire, these conditions can be rewritten as:

(5.2) $$\ln P_k - \ln P_l = \ln(a/b * L/K)$$

$$\ln P_f - \ln P_l = \ln(c/b * L/F)$$

$$\ln Y = \ln A + a \ln K + b \ln L + c \ln F$$

In the absence of technical or allocative inefficiencies, equations (5.2) will compose the original system to be estimated.

A firm's production process can be inefficient in two ways, only one of which can be detected by an estimated production function alone. Technical inefficiency occurs when the firm fails to maximize output given its input bundle. This results in a proportional overutilization of all inputs. Allocative inefficiency occurs when the firm does not equate $MC_i = MC_j$ for i different from j; i.e. when first order conditions do not hold exactly. This results in utilization of inputs in the wrong proportions, given input prices. If we assume that the firm is allocatively efficient, we can derive a cost function as follows:

1. From the first order conditions:

(5.3) $$K^* = P_l/P_k * a/b * L$$

$$F^* = P_l/P_f * c/b * L$$

2. From the C-D production function:

(5.4) $Y = A K^a L^b F^c e^{v-u}$,

we obtain L^*,

(5.5) $L^* = Y^{1/r} A^{-1/r} (P_1/P_k*a/b)^{-a/r} (P_1/P_f*c/b)^{-c/r} e^{-(v-u)/r}$

3. Substituting L^* in the input demand equations and simplifying:

(5.6) $K^* = A^{-1/r} Y^{1/r} (P_1/P_k*a/b)^{(r-a)/r} (P_1/P_f*c/b)^{-c/r} e^{-(v-u)/r}$

$F^* = A^{-1/r} Y^{1/r} (P_1/P_k*a/b)^{-a/r} (P_1/P_f*c/b)^{(r-c)/r} e^{-(v-u)/r}$

4. Substituting F^* and K^* in the cost equation, and normalizing with respect to P_1 (in logarithmic form):

(5.7) $\ln (C/P_1) = G + 1/r \ln Y - a/r \ln(P_1/P_k) - c/r \ln(P_1/P_f) - 1/r(v-u)$

where

$G = \ln r - 1/r \ln A - 1/r \ln (a^a + b^b + c^c)$

$r = a + b + c$

P = price of capital, labor, fuel

C = total cost of production

5. When estimating a short run cost function, K_0 is fixed, and the cost function can be derived following the same procedure as for the long run cost function; presented in logarithmic form the short run cost function is as follows (normalized with respect to P_1):

(5.8) $\ln (C-P_kK_0)/P_1 = G - a/r \ln K_0 + 1/r \ln Y - c/r \ln(P_1/P_f) - 1/r (v-u)$

where

$G = A \quad (c/b)^c + (c/b)^b {}^{-1/r}$

In order to incorporate technical and allocative inefficiencies in the estimating equations, we can amend eq. (5.2) as follows:

$$(5.9) \quad \ln Y = \ln A + a\ln K + b\ln L + c\ln F + (v-u)$$

$$\ln P_k - \ln P_l = \ln(a/b * L/K) + e_2$$

$$\ln P_f - \ln P_l = \ln(c/b * L/F) + e_3$$

The stochastic production function specifies output of each firm as being bounded above by a frontier that is stochastic in the sense that its placement is allowed to vary randomly across firms. The firm is allowed to be technically inefficient relative to its own frontier. Interfirm variation of the frontier captures the effects of exogenous shocks beyond the control of the firm. The disturbance term (v-u) in eq. (5.3) is made up of two parts: a symmetric component v capturing this randomness outside the control of the firm, and a one-sided component u capturing randomness under the control of the firm. The latter is technical inefficiency. Allocative inefficiency appears in eq. (5.9) as the disturbances from the exact satisfaction of the first order condition for cost minimization, ($e_2 >< 0$, $e_3 >< 0$).

In order to discriminate among the various components of the residuals, we need to make assumptions about v, u, and e_i. Several distributions of the disturbances can be hypothesized. As mentioned in the third chapter, the choice of a distribution for the disturbances is done without much theoretical guidance. Schmidt and Lovell (1979, p.349) state that «there is no particular good reason to assume a given distribution for the disturbance term. The only real solution is to try various alternative distributions and see which fits best.»[14]

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[14]Aigner, Schmidt and Lovell (27) estimated a production function assuming disturbance (u) to be distributed with a half-normal and an exponential. The results indicated that the parameters of the production function were very close. As for the estimates of technical inefficiency, they were also very close.

This research assumes that the distribution of the one-sided error term, u, is a positive half-normal; it is the absolute value of a variable distributed as N $(0, s^2_u)$. The symmetric component v is assumed to be distributed as N $(0, s^2_v)$. It is assumed that there is no systematic tendency to over or under utilize any input relative to any other input given true internal prices; therefore, $e_i = (e_2, e_3)$ has a multivariate normal distribution with mean zero and covariance matrix Σ [15]. It is also assumed that e_i is independent of v and u[16].

The following information is obtained from estimate of eq. (5.9) (Schmidt and Lovell, 1979, p. 356); estimates of:

(a) parameters of the production function,

(b) s^2_v, which specifies the stochastic character of the production function,

(c) s^2_u, from which we can obtain an estimate of the mean of u, which represents the average deviation from the frontier due to technical efficiency,

(d) Σ , which specifies the distribution of the disturbances in the set of first order conditions, from which allocative efficiency can be measured.

The MLE of eq.(5.9) requires a proper likelihood function. This

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[15]The Averch-Johnson effect, if it exists, be explicit in the input demand functions. Therefore, the e_i represents deviations from the optimal input use after the A-J effect is controlled.

[16]Those assumptions are taken from Schmidt and Lovell (1979).

likelihood function can be derived from the assumptions made about the disturbance terms of the original system (v, u, e_i). By assumption, the density of e_i is the density of $N(0,\Sigma)$:

$$(5.10)\ g(e_i) = (2\pi)^{-(n-1)/2} [\Sigma]^{-1/2} \exp -1/2\ e'\Sigma^{-1}e$$

The density of (v-u) represents the sum of a symmetric normal random variable and a truncated normal random variable:

$$(5.11)\ f(v-u) = 2/s\ f^*((v-u)/s)\left[1 - F^*((v-u)ds^{-1})\right]$$

where $s = \sqrt{}(s^2{}_u + s^2{}_v)$; $d = s_u/s_v$; and $f^*(\cdot)$ and $F^*(\cdot)$ are the standard normal density and the cumulative distribution functions, respectively. Since (v-u) is assumed to be independent of e_i, the joint density of e_i and (v-u) is the product of $g(e_i)$ and f(v-u). The likelihood function is, therefore:

$$(5.12)\ l=(2\pi)^{-1}[\Sigma]^{-1/2}\exp -1/2\left[e'\Sigma^{-1}e\right]\ 2/s\ f^*((v-u)/s)$$
$$\left[1-F((v-u)d/s)\right]$$

the relevant log-likelihood function becomes:

$$(5.13)\ L = -\ln(2\pi)-1/2\ln[\Sigma]-1/2\Sigma(e_t'\Sigma e_t)+\ln(2/s)$$
$$+ \quad \ln f((v-u)/s) + \ln 1-F((v-u)d/s)$$

where

Σ : represents the variance-covariance matrix of e_i

$s^2{}_2$: $(\ln K- \ln L - \ln P_l/P_k - \ln a/b)^2$

$s^2{}_3$: $1/TS^T(\ln K - \ln F - \ln P_f/P_k - \ln a/c)$

This log-likelihood function can be maximized numerically with respect to the parameters (A, a, b, c, s, r and Σ) to obtain the maximum likelihood estimates. We can find the optimizing values with an algorithm such as Davidon-Fletcher-Powell (DFP).

FIFTH CHAPTER

DATA ANALYSIS AND RESULTS

1- Introduction

The second chapter outlines relations between property rights structures of various ownership forms and the concept of efficiency; while the third and fourth chapters have reviewed the empirical models used to measure efficiency, and presented the technology and models to be estimated, respectively. This chapter will present data and results from estimation of the models developed in previous chapters. The second section restates the testing procedure. The third section explains the data used. The fourth section presents the estimations and interprets the results with respect to efficiencies of various organizational forms.

2- Presentation of the models

2.1 Dummy variable model

Several models will be estimated to measure efficiencies of ownership structures. First, since most of the empirical literature testing relative efficiency of ownership structures is based on estimation of a dummy variable model, the following cost function model is estimated:

$$(5.1)\quad Ln(C/P_l) = G + 1/r \ ln\ Y - a/r \ ln\ (P_l/P_k) - c/r \ ln(P_l/P_f) + d_1 V + d_2 \ Pub + d_3 \ Coop + e_1$$

where

$Ln(C/P_l)$ - total cost of production normalized with respect to price of labor, in logarithmic form,

G - intercept term,

Y - output,

$P_{k,l,f}$ - price of capital, labor, fuel,

V - dummy variable accounting for vintages of technology, 0 for the first vintage embodied in plants built between 1965-1968 and 1 for plants built between 1969-1973,

Pub - dummy variable accounting for ownership structure, 0 for private and cooperative utilities, and 1 for public utilities,

Coop - dummy variable accounting for ownership structure, 0 for private and public utilities, and 1 for cooperative utilities,

r - returns to scale (a + b + c)

G, r, a, b, c, d_1, d_2, d_3 - parameters to be estimated,

e_i - disturbance terms with $N(0, s^2_e)$.

This cost function is derived from a Cobb-Douglas production function under assumption of cost minimization. This model will be estimated using OLS, and will provide us with baseline measures of efficiency between ownership structures. The information about relative efficiency is captured by the coefficients of the dummy variables d_2 and d_3.

2.2 Stochastic frontier Cobb-Douglas cost function

a) Long run cost function

A second set of models is estimated using a stochastic frontier Cobb-Douglas cost function. Since our data set (to be described in the next section) most likely captures a combination of ex ante and

ex post technology we estimate both long run and short run cost functions. Assuming allocative efficiency, the long run cost function derivable from the Cobb-Douglas production function is as follows:

$$(5.2)\ Ln(C/P_1) = G + 1/r \ln Y - a/r \ln (P_1/P_k) - c/r \ln (P_1/P_f) + d_1 V - 1/r (v-u)$$

where

G, r, Y, $P_{k,1,f}$, V, a, c, are as previously defined,

v - symmetric component of the disturbance term capturing randomness outside the control of the firm, distributed as $N(0, s^2_v)$,

u - one sided (non positive) component capturing randomness under the control of the firm, distributed half-normal with $N(0, s^2_u)$.

The stochastic frontier cost function presented in eq. (5.2) contains factor prices as arguments. Its estimation provides evidence on the magnitude and cost of total inefficiency. However, with this cost function model it is not possible to decompose the estimates of total cost inefficiency into its technical and allocative portion. The long run cost function is estimated for each organizational form.

The estimation procedure followed to estimate eq.(5.2) uses MLE assuming that the distribution of the one sided error term, u, is half normal while the symmetric component, v, is assumed to be normally distributed. The density function of (v-u) is (Aigner, Schmidt and Lovell, 1977, p. 26):

$$(5.3)\ f(v-u) = 2/s\ f^* (v-u)/s \quad 1 - F^*((v-u)ds^{-1})$$

where $s = (s^2_u+s^2_v)^{1/2}$; $d = s_u/s_v$; f^* and F^* are the standard normal density and the cumulative distribution function respectively.

The log-likelihood function using the density function (5.3) can be maximized numerically with respect to the parameters (G, a, c, r, s, d) in eq. (5.2) and eq. (5.3) to obtain the maximum likelihood estimates. The Davidon-Fletcher-Powell (DFP) algorithm is used to obtain the optimizing values.

Using the same stochastic frontier Cobb-Douglas cost function, we estimate a model for private regulated electric utilities that incorporates a regulatory constraint. Following Pescatrice and Trapani (1980, p. 261), we assume that the internal cost of capital is defined as follows:

(5.4) $P^I_k = P_k - z (p - P_k)/(1 - z)$

where

P^I_k - internal price of capital for private utilities,

P_k - market price of capital (to be defined in the next section),

z - regulatory constraint multiplier,

p - average rate of return by firm in current and previous two years.

The regulatory constraint, z, is a measure of the tightness of regulation. In the case where the allowable rate-of-return regulation is set above the profit maximizing level, then regulation is ineffective and $z = 0$. At the other extreme, if the allowable rate-of-return is set equal to P_k, then $z = 1$. If z is binding on the private firm ($0 < z < 1$), the firm minimizes the internal total cost, $C^I = P_1L + P_fF + P^I_kK$. The estimation procedure follows the estimation of the long run cost function except that P_k is replaced by P^I_k in eq.(5.2). To search for the appropriate specification of internal price of

capital, we use the method employed by Pescatrice and Trapani, whereby z is assigned the values 0, 0.2, 0.5, 0.8 (Pescatrice and Trapani, 1980, p. 268)[1]. The information obtained from such a model permits measurement of inefficiency while the regulatory distortion is controlled for.

b) Short run cost function

Since our data are likely to capture a combination of ex ante and ex post technology we need to estimate a short run stochastic frontier Cobb-Douglas cost function. The model is as follows:

$$(5.5)\quad \text{Ln}\ (C-P_kK_0)/P_1 = G - a/(b+c)\ \ln K_0 + 1/(b+c)\ \ln Y$$
$$- c/(b+c)\ \ln (P_1/P_f) - (v-u)/(b+c)$$

where all parameters are as previously defined, and K_0 is the fixed quantity of capital used at the plant.

The estimation of such a model will be done using MLE technique and the likelihood function presented in eq.(5.3) following the procedure described with regard to eq. (5.2). This formulation of the cost function has the advantage of eliminating the price of capital from the estimation, and P_k is difficult to measure, as we will see in the next section. Furthermore, the regulatory distortion problem over the internal P_k is solved. The estimation of this short run cost function provides estimates of the parameters of the cost function and an estimate of mean inefficiency for each organizational form.

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[1]The value of z is unknown. Therefore, we assign different values to z, and an overall significance of the models estimated with various values of z (0.0, 0.2, 0.5, 0.8) is computed comparing R^2, log-likelihood value and F statistics. The appropriate value of z is selected given the highest values on those three statistical tests.

2.3 System of equations

a) Long run Cobb-Douglas production function

In order to obtain separate estimates of technical and allocative efficiencies for each ownership structure, we estimate a system of equations as presented in eq.(5.6):

$$(5.6)\quad \ln(Y) = A + a\ln(K) + b\ln(L) + c\ln(F) + (v-u)$$

$$\ln(L) - \ln(K) = \ln(b/a * P_k/P_l) + e_2$$

$$\ln(L) - \ln(F) = \ln(b/c * P_f/P_l) + e_3$$

where

Y - output

K - capital

L - labor

F - fuel

$P_{k,l,f}$ - prices of capital, labor and fuel respectively,

v - symmetric component capturing randomness outside the control of managers,

u - one sided component capturing error under the control of managers,

e_i - disturbances from the exact satisfaction of the first order conditions with $N(0, s^2_e)$,

A, a, b, c - parameters to be estimated.

Technical inefficiency appears in the long run production function and is measured by u. In order to calculate mean technical inefficiency from the ancillary parameters we use the following formulas[2]

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[2]Stevenson, 1980, p. 60.

(1): $s_u = s\,[1/\sqrt{(1/(d^2+1))}]$, (2) $E(u) = (\sqrt{2}/\sqrt{\pi}) * s_u$; where $d = s_u/s_v$, $s = \sqrt{(s^2_u+s^2_v)}$.[3] Estimates of d and s (the ancillary parameters) are obtained from the maximized likelihood function. Estimates of E(u) can be interpreted as measures of mean inefficiency, while E(u)/r represents the cost of mean technical inefficiency where r measures the return to scale[4]. Allocative inefficiency is introduced in the first-order conditions. In this model, the disturbances in the first-order equations will be interpreted as measures of over/under capitalization with respect to fuel and labor. The cost of technical inefficiency is measured as (1/r*u), while the cost of allocative inefficiency is measured as E-ln(r)[5]. Total cost of inefficiency is the summation of the technical and allocative components.

We can estimate the system of equations (5.6) using MLE deriving a proper likelihood function. Following Schmidt and Lovell (79, p.349), the density function for (v-u) is the same as the one shown

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[3](1) $s = (s^2_u + s^2_v)^{1/2}$
(2) $d = s_u/s_v$
Following Aigner, schmidt and Lovell (1977, p. 26), this particular parameterization of s and d (obtained from the derivation of the density function of v-u) is convenient because d can be interpreted to be an indicator of the relative variability of the two sources of random error that distinguish firms from one another. From those definitions we can derive the formulas for s_u and E(u) as follows:
(3) $s_v = s_u/d$
(4) $s = (s^2_u + s^2_u/d^2)^{1/2}$
(5) $s = s^u\,(1 + 1/d^2)^{1/2}$
(6) $s_u = s\,[1/\sqrt{(1+1/d^2)}]$
while $E(u) = (\sqrt{2}/\sqrt{\pi})*s_u$ is derived from the moments of u.

[4]The formula for the cost of mean technical efficiency is derived from the Cobb-Douglas cost function (see eq. 5.7 in chapter 4).

[5]E-lnr is the estimated cost of allocative inefficiency where $E = c/r * e_3 + b/r * e_2 + \ln a + c * \exp(-e_3) + b * \exp(-e_2)$, where a, b, c are parameters of the production function, e_2 and e_3 are the mean residuals from the exact minimization of the first order conditions in eq. (5.6). Lnr is the natural logarithm of the estimate of the return to scale (r=a+b+c).

in eq.(5.3). We assume that $e_i=(e_2, e_3)$ has a multivariate normal distribution:

(5.7) $f(e_i) = (2\pi)^{-1} [\Sigma^{-1}] \exp[-1/2\ e'\Sigma^{-1}e\ ].$

where $\Sigma = [S22\ \ S33/S23\ \ S32]$ is the variance-covariance matrix of e_i. By assumption, (v-u) and e_i are assumed to be independent. The joint density function is the product of f(v-u) and $f(e_i)$:

(5.8) $f[(v-u),e)=(2\pi[\Sigma])^{-1} \exp[-1/2e'\Sigma^{-1}e\ ](2/s)\ f^*[(v-u)/s)]$

$[1 - F^*((v-u)d/s)].$

The likelihood function associated with eq.(5.6) and eq. (5.8) can be maximized numerically with respect to the parameters (A, a, b, c, d, s, Σ). These estimates will be consistent and asymptotically efficient.

b) Short run production function

The system of equations is also estimated using a short run production function when K_0 is fixed:

(5.9) $Ln(Y) = G + a \ln K_0 + b \ln L + c \ln F + (v-u)$

$Ln(F) - Ln(L) = \ln [P_1/P_f * c/b] + e_2$

where all parameters are as previously defined.

From the estimation of the system of equations (5.9), using MLE and the log-likelihood function derived from eq. (5.8), we obtain estimates of the parameters of the production function as well as the ancillary parameters from which we can calculate mean technical and allocative inefficiencies for each type of ownership structure. As before, such model has the advantage of eliminating the measurement problem of the price of capital.

2.4 Models to be estimated

In summary, the following models will be tested.

1. cost function with dummy variable
2. stochastic frontier cost function
   - 2.1 long run cost function
     - 2.1.1 private utilities
       - a) no adjustment for regulation
       - b) adjustment for regulation
         - d: 0.0, 0.2,.0.5,.0.8
     - 2.1.2 public utilities
     - 2.1.3 cooperative utilities
   - 2.2 short run cost function
     - 2.2.1 private utilities
     - 2.2.2 public utilities
     - 2.2.3 cooperative utilities
3. system of equations
   - 3.1 long run production function
     - 3.1.1 private utilities
       - a) no adjustment for regulation
       - b) adjustment for regulation
         - d: 0.0, 0.2, 0.5, 0.8
     - 3.1.2 public utilities
     - 3.1.3 cooperative utilities
   - 3.2 short run production function
     - 3.2.1 private utilities
     - 3.2.2 public utilities
     - 3.2.3 cooperative utilities

3- Data description

To measure comparative efficiency of various ownership structures, we have selected the steam-electric generation industry in the U.S.. This industry shows interesting characteristics: (1) three different ownership structures are generating electricity using the same technology (steam-electric generation with fossil fuels); (2) standardized data for all three types of firms are available (production as well as financial data); (3) technology of steam-electric utilities has been studied for over 25 years.

The data are measured at the plant level[6]. All plants built after 1965 were considered. Plants prior to 1965 could not be used because the Federal Power Commission did not publish production data relative to cooperative utilities. Plants with joint ownership were dropped. Those plants selected are most likely to be of base load characteristics rather than peak load[7]. The data for all three types of ownership are a pooling of cross-section and time series of plants. They cover new plants built between 1965 and 1973[8]

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[6]We have to recognize the influence of the aggregation process (the firm being a gathering of plants) on the estimation of the characteristics of technology as well as measures of technical and allocative inefficiencies. For instance all measures of cost inefficiency are directly related to measures of economies of scale. Furthermore Aigner et all (77) have estimated technical inefficiency on aggregated data and found very little evidence of it.

[7]It makes sense to assume that new plants will be of base load characteristics since technical change is mostly embodied in electricity generation. Firms will have an incentive to use new plants (most efficient ones) to satisfy base load demand if they behave as cost minimizers.

[8]In this industry effects of technological changes are embodied in capital. Thus, following conventional practice we have subdivided this sample in two vintages according to the data of each plant's initial year of operation.

for which the necessary data are available. The data are from the first full year of operation through the fifth year. There were 37 plants built by privately owned electric utilities during that period, providing 150 observations. Consumer cooperative utilities constructed 16 plants, for 71 observations. Publicly owned utilities were the least active group, building 9 plants from which 33 observations were obtained.

Strong differences exist among the studies surveyed with respect to measurement of the price and cost of capital. Dhrymes and Kurz (1964) and McFadden (1964) estimated cost of capital as the estimated value of the plant less non capital cost divided by a measure of capital input. Nerlove (1963), Cowing (1974), Christensen and Greene (1976) and Lovell and Schmidt (1979) estimated cost of capital as the nominal interest rate on the firm's bonds prior to plant installation. Petersen (1975) and Sowell (1978) estimated cost of capital using the Jorgenson formulation of the annual rental price of capital. Wilson (1976) used a discounted cash flow model to evaluate the cost of common stock which he used as a proxy for cost of capital. Finally, Stevenson (1980) and Pescatrice and Trapani (1980) used a weighted average of the cost of debt, preferred and common stock to estimate the cost of capital. Stevenson used a discounted cash flow model to estimate the financial cost of common stock capital while Pescatrice and Trapani measured the cost of equity capital by dividing dividend payments by the equity capital.

The cost of capital is the minimum rate of return necessary to attract capital, and it can be defined as the expected rate of return prevailing in capital markets on alternative investments

of equivalent risks[9]. The cost of capital is a forward-looking concept since it is an expected rate of return. Furthermore, it is an opportunity cost concept which depends on the risk of the investment and is determined in capital markets. The cost of capital for a company is a weighted average of the costs of capital for the various investments of which the company is comprised. The capital structure characterizing a company is a mix of debt and equity (common and prefered stocks). According to Kolbe and Read (1984, p.44) the cost of common equity capital is what poses a problem in estimating the cost of capital. Return on preferred equity is equal to preferred dividends divided by the book value of preferred stock while the return on debt is equal to the interest expenses divided by the book value of debt. Therefore, they focus only on discussing problems related to estimates of cost of common stock. The cost of preferred equity and the cost of debt can be observed directly in the market because the promised amount and timing of preferred dividends and interest are fixed. Several methods to estimate cost of common equity capital are reviewed and evaluated by Kolbe and Read (1984), but only two will be discussed in this chapter, comparable earnings and discounted cash flows models, since those are the methods found in the empirical literature.

The comparable earnings (CE) method uses rates of return on equity (ROE) of comparable risk investments. ROE is calculated by taking net income earnings less interest and taxes, and preferred dividends; and dividing by the summation of common stock, paid-in

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[9]This paragraph draws from Kolbe et al. (1984), and from Wilson (1976).

capital and retained earnings, less treasury stocks. Common stock is the par-value of common shares issued, retained earnings is the cumulative net income that has not been distributed as either preferred or common dividends, and paid-in-capital is the excess over par value that was received when the shares were issued. Treasury stocks represent the book value of common shares that have been reacquired by the company since they were issued. Kolbe and Read (p. 45) argue that comparable earnings is a poor method to evaluate the true cost of capital from the point of view of the regulator: (1) it is hard to select firms of comparable risks, (2) the cost of capital is inferred from the book rate of return for these comparable risk companies, (3) the book rate of return is based on generally accepted accounting principles but it will only equate the true rate of return by accident (accountants exercise considerable discretion in the application of generally accepted accounting principles), (4) book earnings do not distinguish between excess and normal returns since no adjustment for security prices is considered, (5) the accounting concepts of income and value are not the same as the corresponding economic concepts (asset values are historical costs and are different from market values or replacement costs), (6) depreciation to write down systematically the original cost of assets is different from the change in the value of an asset, and (7) accounting errors due to inflation vary across asset life. According to Kolbe and Read (p.49), the most serious problems are the historical cost principle and the accounting depreciation schedule.

The objective of our research is not to determine what should be the appropriate rate of return that should be allowed to the regula-

ted private firm. Instead we are interested in determining the cost of capital facing a firm. The problems outlined above are related to estimates of the cost of common stock, which represents only one type of capital used by private firms. Long term debt is the most important source of fund, contributing more then 50% of all capital used. Therefore, the comparable earnings method, which was the most widely used method of estimating cost of capital by regulators through the late 70's, can still be appropriate to estimate cost of capital for private regulated firms in our study.

The discounted cash flow model (DCF) estimates the cost of equity capital as: $r = D_1/P_0 + g$, where r is the estimated cost of capital, D_1 is the dividends that stockholders received in period 1, g is the estimated long term growth rate of dividends and P_0 is the common stock price at the end of period 1. A potential problem with the DCF model is the steady growth assumption. It is difficult to apply when the company is in a transition between growth paths. On average, the DCF method gets good results in estimating cost of capital when times are stable, and is widely used by regulatory commissions (much less so in the early 70's) (Kolbe et al., p.60).

Even though the DCF method seems superior to the CE method, we used the CE method because (1) most regulatory commissions used such method to determine the allowed rate of return between 1965-1975, (2) the distortion is affecting only a portion of the capital structure and (3) the data required were more easily available.

The estimation of the cost of capital for publicly-owned and cooperatives utilities is a simpler problem since their capital

structures are fairly straightforward. In the case of publicly-owned utilities, the structure of capital is composed primarily of long term debt, retained earnings, and other government sources of capital. The cost of long term debt is readily known, and the cost of equity is approximated using the rate on treasury bills maturing in 10 years. The structure of capital of cooperative utilities is even simpler since it is composed almost entirely of long term debt obtained through REA at a rate set by law of 2% until 1971. For many cooperatives, their loans and utility plant (at cost) are almost identical. When cooperatives showed equity, its cost was approximated using the same rate of treasury bills maturing in 10 years as used for public utilities.

In this research the variables used in estimation were measured as follows. Output is the net generation of electricity measured in millions of KWH/year. Most other studies of electric utilities have used such a measure of output (see Kopp and Smith (1980), Schmidt and Lovell (1979), Pescatrice and Trapani (1980), Dhrymes and Kurz (1964), McFadden (1964), Nerlove (1963), Petersen (1975), Christensen and Greene (1976)). Capital was measured as cost of plants in thousands of dollars[10] (see Lovell and Schmidt (1979), Pescatrice and Trapani (1980), Komiya (1962), Courville (1974), Barzel (1964), McFadden (1964), Belinfante (1969)). Other measures, such as installed generating equipment (also referred to as nameplate capacity) (Barzel (1964)) and net continuous plant capability (Sowell (1978) were used. Fuel was measured in millions of BTU burned per year. All researchers referred to previously measured input fuel in terms of

[10]The price of land and land rights is excluded.

BTU burned per year. Labor was measured in average numbers of employees * 2000 hours per year. Again most researchers have used this measure. The price of fuel was measured as cost per million BTU, measure which is provided by the FPC on a plant basis. The price of labor was measured as total cost of maintenance production divided by total hours worked per year. A few researchers used a regional average wage as a proxy for price of labor (Nerlove (1963), Lovell and Schmidt (1979), Pescatrice and Trapani (1980)). Those studies used an estimate of the manufacturing wage rate of the state in which the firm operates. The price of capital for private regulated firm was measured as the sum of interest on long term debt + dividend on preferred and common stock divided by long term debt + equity (common and preferred stocks issued). The price of capital for publicly owned utilities was measured as the sum of interest on long term debt + cost of equity capital[11] divided by long term debt + (investment of municipality + retained earnings). The price of capital for cooperative utilities was measured as the sum of interest on long term debt + cost of equity capital divided by long term debt + total net worth.

The descriptive characteristics of the sample used for the three types of ownership forms are presented in table 1:

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[11]As a proxy for cost of equity capital cost of long term government bond maturing in 10 years has been used for public and cooperatives.

Table 1
Descriptive statistics (mean)
standard deviation in parentheses

	private[12]	public	cooperative
output (000,000 Kwh)	1823.5 (993)	1281.1 (1115)	1064.1 (781)
capital ($)	46,996,000 (29,738,000)	33,887,000 (28,208,000)	27,100,000 (17,094,000)
P_k (%)	0.0732 (0.0214)	0.0521 (0.0109)	0.0208 (0.0048)
fuel (000,000 BTU)	18,068,000 (9,414,900)	12,721,000 (10,624,000)	11,141,000 (7,921,900)
P_f ($/000,000 BTU)	0.475 (0.414)	0.542 (0.566)	0.321 (0.327)
labor (hours/plant/year)	100,720 (51,626)	116,550 (89,643)	79,352 (42,598)
P_l ($/hours)	5.636 (3.659)	4.181 (3.055)	3.794 (2.37)

Models will be estimated with respect to samples of plants of public utilities, cooperative utilities, small plants private utilities, large plants private utilities as well as full sample of private plants.

4- Results and interpretations

4.1 Dummy variable cost function

The first model estimated is the Cobb-Douglas cost function with dummy variables on a pooling of data for all three types of

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[12] The full sample of private plants shows much higher mean values for data measurements. Therefore, to make samples more comparable, the private sample has been divided into plants with output smaller than 3500 millions of KWH/year, and into plants with output larger than 3500 millions of KWH/year. The first sample contains 75 observations and shows a mean output of 1823.5 millions of KWH, while the sample of large plants has a mean output of 6099.8 millions of Kwh/year.

firms. Results are presented in Table 2.[13]

Table 2
OLS estimates of Cobb-Douglas cost function,eq.5.1,
with dummy variables
using a pooled of samples (253 observations)
t-ratios in parentheses

constant K	output 1/r	Pl/Pk a/r	Pl/Pf c/r	V d_1	Pub d_2	Coop d_3
10.687	0.844	-0.138	-0.722	0.125	-.013	-.129
(109.25)	(63.08)	(-6.84)	(-43.6)	(6.37)	(-.42)	(-4.92)

R-square : .978
F-statistic : 1841.4

The first dummy variable accounts for vintages; all plants built between 1965-1968 take a 0 value while all plants built between 1969-1973 take a value of 1. The results are statistically significant and indicate that the second vintage group shows higher cost of production than the first vintage group. Moreover, the cost difference between the two vintage groups represents 13.3%. The other two dummy variables account for ownership structures. Private firms are the control group, Pub has a value of 1 for public firms and 0 for privates and cooperatives, Coop has a value of 1 for cooperatives and 0 for privates and publics. Both dummy variables have negative signs indicating that private firms are the least efficient type of ownership structure. Only the coefficient of Coop is significantly different from zero. Moreover, its magnitude indicates a difference of 13.76% between cost of production for private and cooperative

[13]When this cost function is estimated using the sample of small private plants combined with the sample of public and cooperatives, the cost difference between private and cooperative utilities reduces to 10.3% and is statistically significant.

utilities[14].

4.2 Stochastic frontier Cobb-Douglas cost function

a) Long run cost function

Results from the second model eq. 5.2, are obtained from maximum likelihood estimates of the stochastic frontier Cobb-Douglas cost function assuming that firms are allocatively efficient. Estimates are presented in Tables 3 and 4.[15] The cost function has been estimated for each sample of types of firms. Furthermore, in the case of the private regulated firms, the model has also been estimated to account for the regulation effect by using the internal price of capital, as presented in equation (5.4)[16]. The regulatory constraint multiplier, z, was given the values of 0.0, 0.2, 0.5, 0.8 while p (the allowed rate of return) was measured as an average of actual

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[14]Cost difference between private and cooperative:

$$(C_{co} - C_{pr})/C_{pr} = (e^{a+b} - e^{a})/e^{a} = e^{b} - 1$$
$$= e^{.129} - 1 = 1.1376 - 1 = .1376.$$

Therefore, the cost difference between cooperative and private utilities is 13.76%.

[15]Those results were obtained by numerical techniques which implies maximizing the log-likelihood function by choice of the unknown parameters G, a, c, r, s, d. Starting values are provided by estimates of the OLS/moments method. The program used is Limdep (written by W. Greene). The maximization of the likelihood function was done with the Davidon-Fletcher-Powell algorithm (Greene, 1980, pp. 41.1-41.5) which is very popular and has proved very efficient in many applications (Judge, Griffiths, Hill and Lee, 1980, p. 734). The estimation of the asymptotic variance of MLE is calculated from the inverse of the information matrix (Kmenta, 1971, p. 160). Limdep uses the Berndt et al. estimator to calculate the asymptotic variance matrix for the MLE when FRON is used to estimate stochastic frontier cost function (Greene, 1980, p. 16-1). When the User Defined Minimization routine is used to estimate the system of equations (see results presented in tables 10, 11, 12), Limdep minimizes the likelihood function using DFP and the information matrix is approximated using a formula given in Greene, 1980, p. 41-4.

[16]Only the full sample of private plants was used to estimate the long run cost function while accounting for the regulatory effect.

rates earned by the firm during the current and previous two years (Pescatrice and Trapani (1980, p.275).

The results from the stochastic frontier long run cost function give us estimates of the parameters of the cost function (from which we could derive parameters of the production function) and the ancillary parameters, from which we can calculate the mean technical inefficiency and its cost[17]. Mean inefficiency was lowest for cooperatives, 7.8%. Publicly-owned utilities show a mean inefficiency of 13.1%. However, results obtained for private utilities after dividing the sample into small and large plants show a mean inefficiency of 13.9% for smaller private utilities, showing a cost due to mean technical inefficiency of 11.27%. The cost due to mean inefficiency was lowest for cooperatives, 6.5%, with public utilities showing 11.6% of its cost being caused by its technical inefficiency. The larger plants show a mean inefficiency of 27.14% for a cost of mean technical inefficiency of 27.2%. The introduction of the regulatory constraint in the estimated cost function (using the full sample of private plants) affected the results for mean inefficiency only slightly. Mean inefficiency was lowest for private utilities when $z = 0.2$, and $E(u) = 20.11\%$, as table 4 shows[18]. Only when z was equal to 0.8 did the estimation of mean inefficiency increased to

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[17]See footnote # 3 for a discussion of mean technical inefficiency and its cost.

[18]The highest R^2_a value is obtained when $z=.2$ which also shows the highest value of lnL and the highest F statistics.

	R^2_a	lnL	F statistics
z = 0.0	.910	44.5	378.7
z = 0.2	.914	45.6	385.5
z = 0.5	.908	43.6	358.9
z = 0.8	.881	13.7	171.9

24.1%. The cost of mean technical inefficiency is highest for private utilities, around 16.7% when z = .2.

Table 3
Stochastic frontier
Long run Cobb-Douglas cost function
(asymptotic t-ratios in parentheses)

type of owner.	constant K	output l/r	P_l/P_k a/r	P_l/P_f c/r	V d_1	R^2_a
priv (z=0)	10.490	0.8359	-0.153	-0.679	.183	0.910
(150 observ.)	(61.4)	(29.5)	(-3.15)	(-15.2)	(4.89)	
priv(z=.2)	10.557	0.831	-0.155	-0.679	.169	0.914
(150 obs.)	(59.5)	(29.3)	(-3.33)	(-15.6)	(4.61)	
priv(z=.5)	10.653	0.817	-0.141	-0.684	.129	0.908
(146 obs.)	(56.3)	(28.6)	(-3.53)	(-15.6)	(3.49)	
priv(z=.8)	10.466	0.781	-0.027	-0.708	.123	0.881
(98 obs.)	(39.1)	(20.8)	(-1.14)	(-11.3)	(2.05)	
priv (small)	10.889	0.807	-0.136	-0.736		0.958
(75 obs.)	(50.48)	(33.2)	(-3.39)	(-19.9)		
priv (large)	9.235	1.002	-0.158	-0.711		0.746
(75 obs.)	(6.17)	(4.95)	(-1.09)	(-6.42)		
public firms	10.047	0.880	-0.018	-0.819	-.113	0.990
(33 observ.)	(38.6)	(31.9)	(-0.26)	(-13.9)	(-1.1)	
cooperatives	10.181	0.829	-0.025	-0.777	.039	0.983
(71 observ.)	(80.6)	(56.1)	(0.91)	(-47.6)	(1.97)	

Table 4
Stochastic frontier
Long run cost function
Estimates of ancillary parameters (technical and cost inefficiencies)
(asymptotic t-ratios in parentheses)

type of ownership	sigma(s)	lambda(d)	E(u)	E(u)/r
private	.2767	2.399	.2038	.1704
	(34.3)	(7.86)	(26.66)	
priv (reg = 0.2)	.2737	2.361	.2011	.1677
	(34.8)	(8.15)	(27.21)	
priv (reg = 0.5)	.2738	2.319	.2006	.1639
	(34.97)	(8.71)	(28.30)	
priv (reg = 0.8)	.3257	2.482	.2410	.1883
	(23.9)	(5.66)	(19.79)	
priv (small)	.1918	2.236	.1397	.1127
	(4.53)	(2.64)	(3.79)	
priv (large)	.3723	2.248	.2714	.2725
	(15.6)	(4.99)	(14.18)	
public	.1670	5.133	.131	.116
	(6.37)	(1.61)	(6.35)	
cooperative	.1033	2.995	.0782	.065
	(5.79)	(2.00)	(5.04)	

The estimated inefficiencies for private utilities are in line with those obtained by Schmidt and Lovell (1979). Using 150 new privately owned steam electric generating plants constructed in the U.S. between 1947 and 1965, they showed a mean technical inefficiency of 15.75% which increased cost of production by 12.6%. Kopp and Smith (1980) estimated a stochastic frontier production function for 43 private and public steam electric generating plants built between 1961 and 1972 using a pooling of cross section and time series data from 1969 and 1973. After dividing the period into two vintages they obtained an estimate of mean technical inefficiency of 18.87% for the oldest vintage while their measure dropped to 5.13% for the youngest

vintage. Finally, Stevenson (1980) estimated a translog cost function using a sample of 81 observations of electrical private utilities in 1970. His result indicates a mean technical inefficiency of 14.86%.

To test whether mean inefficiencies are significantly different from one another we test for the difference between two means[19]. Letting the true mean of the first population be u_1 and the mean of the second population be u_2, the null hypothesis is H_0: $u_1=u_2$. The appropriate test statistic from which we can define the acceptance and the critical region with the help of normal probability tables is[20]:

(5.10) $Z = [(\text{mean } X_1 - \text{mean } X_2) - (u_1-u_2)]/\sqrt{(s^2{}_1/n_1+s^2{}_2/n_2)}$

where X_1 and X_2 are means of the respective samples, $s^2{}_1$ and $s^2{}_2$ are variances of the respective samples, and n_1, n_2 sample sizes.

Table 5
Test for difference between two means

(1) priv(full)/coop	: Z = 68.31
(2) priv(full)/public	: Z = 8.23
(3) public/cooperative	: Z = 13.56
(4) priv(small)/coop	: Z = 13.30
(5) priv(small)/public	: Z = 1.61
critical value of 1.96	

For all tests, except priv(small)/public, between two means presented in table 5, we have to reject the null hypothesis that both means are

[19]Kmenta (1971, p.136)

[20]We can still use that test even though populations are not assumed to be normal since the sample size is greater than 30.

equal at 95% confidence, $Z < 1.96$.

The confidence intervals for the mean inefficiencies of each sample are presented in table 6, and calculated using[21]: (5.11) $X_i - Z_{a/2} * s_i, X_i + Z_{a/2} * s_i$ where X_i is mean technical inefficiency, $Z_{a/2}$ is the critical value and s_i is the asymptotic standard deviation of X_i.

Table 6
Asymptotic confidence interval

private	$.1888 < X_i < .2188$
public	$.0799 < X_i < .1817$
cooperative	$.0478 < X_i < .1086$
private (small)	$.0676 < X_i < .2176$

critical value of 1.96

Results presented in Tables 3-6 suggest that consumer cooperatives are the most efficient type of ownership. Three different tests have been performed: 1) an asymptotic t-test, 2) a test for differences between means, and 3) the asymptotic confidence interval for each sample. From those tests, we can establish that results obtained from stochastic frontier long run cost functions confirm our conclusions derived from the simple dummy variable model. Furthermore, they provide us with the magnitude of mean inefficiency for each ownership structure. However, the effect of size of plants on technical inefficiency cannot be overlooked since mean inefficiency nearly doubles when it is taken into effect.

[21]Following Judge, Griffiths, Hill and Lee (1980, p.753), it is not necessary to assume normally distributed errors for setting up confidence interval as presented in Table 6.

b) Short run cost function

The model presented in equation (5.5) has been estimated, and results are presented in Tables 7 and 8. The estimation of this short run cost function provides estimates of the parameters of the cost function and an estimate of the mean technical inefficiency for private (small plants, large plants and full sample of private plants) and cooperative utilities. This formulation of the cost function eliminates the problem related to the measurement of price of capital since P_k does not appear in the cost function.

Results from this model were obtained from maximum likelihood estimates of the stochastic frontier short run Cobb-Douglas cost function assuming that firms are allocatively efficient.

Table 7
Stochastic frontier
Short run Cobb-Douglas cost function[22]
(asymptotic t-ratios in parentheses)

type of owner.	constant G	output 1/(b+c)	capital a/(b+c)	P_l/P_f c/(b+c)	V d_1	R^2_a
private firms (150 observ.)	7.623 (4.25)	0.724 (5.22)	0.187 (1.23)	-0.886 (-12.7)	0.031 (.32)	0.925
priv(small) (75 observ.)	8.699 (36.6)	0.769 (50.7)	0.118 (6.15)	-0.923 (-98.2)	0.002 (.15)	0.995
priv(large) (75 observ.)	7.714 (2.08)	0.604 (1.65)	0.223 (0.74)	-0.825 (-5.41)	0.107 (.61)	0.784
cooperative[23] (71 observ.)	9.841 (26.9)	0.901 (44.8)	-0.015 (-0.53)	-0.853 (-68.1)		0.984

Table 8
Stochastic frontier
Short run cost function
Estimates of ancillary parameters (technical and cost inefficiency
(asymptotic t-ratios in parentheses)

type of ownership	sigma	lambda	E(u)	1/(b+c)*E(u)
private	.2563 (18.4)	1.319 (9.13)	.1629 (12.82)	.1181
priv(small)	.0590 (6.31)	2.083 (2.17)	.0446 (4.66)	.0343
priv(large)	.3405 (8.04)	1.305 (4.62)	.2213 (6.04)	.1336
cooperative	.1170 (8.72)	5.9727 (1.862)	.0921 (8.459)	.0829

[22]The stochastic frontier cost function could not be estimated using the data for public utilities because the third moments of OLS residuals has wrong sign. Limdep uses the COLS method to generate starting values for MLE, and abort when the third moments of OLS has the wrong sign.

[23]The function could not converge when the stochastic frontier short run cost function was estimated using a dummy variable to account for vintages on cooperative data set.

Inefficiency was lowest for small private plants, 4.46%, while cooperatives showed a mean inefficiency of 9.21%. No results were obtained for public utilities. The cost inefficiency of small private plants represented 3.43% of overall costs while cooperative firms showed a cost inefficiency of 8.29%. However, large private plants are less efficient than small private and cooperatives and show a mean inefficiency of 22.13% . Furthermore, calculating the confidence interval for each sample, using eq. (5.11), we find that the confidence interval for private and cooperative utilities are as presented in table 9:

Table 9
Asymptotic confidence interval

private	$.1381 < X_i < .1879$
priv (small)	$.0246 < X_i < .0603$
priv (large)	$.1494 < X_i < .2932$
cooperative	$.0708 < X_i < .1134$
critical value of 1.96	

4.3 System of equations

a) Long run production function

Estimating the system of equations (5.6) using maximum likelihood, we obtain the results presented in tables 10 and 11.

For private utilities, the system of equations was estimated using the different values of the regulatory constraints for the full sample. The regulatory constraint may be especially important in distinguishing technical and allocative inefficiencies for private regulated firms.

Table 10
System of equations consisting of
Long run production function, and first order conditions
(asymptotic t-ratios in parentheses)

type of ownership	constant A	capital a	fuel c	labor b	V dl	log L (value)
priv(z=0)	-9.681	.301	.685	.0618	-.182	-47.79
150 obs.	(-27.8)	(25.55)	(39.48)	(16.59)	(-4.86)	
priv(z=.2)	-9.679	.292	.694	.0627	-.179	-41.55
150 obs.	(-27.9)	(24.38)	(40.21)	(16.49)	(-4.85)	
priv(z=.5)	-9.546	.266	.711	.0654	-.178	-16.35
146 obs.	(-26.9)	(20.62)	(39.06)	(13.34)	(-4.58)	
priv(z=.8)	-9.131	.205	.747	.0664	-.101	+84.5
98 obs.	(-17.6)	(7.09)	(31.85)	(10.52)	(-1.36	
priv(small)	-11.47	.324	.772	.0512	-.129	-91.5
75 obs.	(-21.1)	(17.6)	(24.75)	(11.75)	(-3.69)	
priv(large)	-5.30	.225	.520	.0599	-.146	-17.4
75 obs.	(-46.9)	(9.78)	(12.56)	(6.98)	(-.114)	
public	-10.94	.251	.804	.0621	-.096	-47.1
33 obs.	(15.65)	(9.58)	(14.2)	(7.23)	(0.82)	
cooperative	-11.05	.172	.876	.0798	-.073	-11.99
71 obs.	(15.63)	(13.67)	(49.0)	(9.65)	(2.66)	

Table 11
Estimates of ancillary parameters
Derived from the system of equations

type of ownership	sigma(s) s	lambda d	S22	S33	S23	s_u
private	.3170 (25.98)	3.822 (3.75)	.365 (7.86)	.605 (9.3)	.308 (6.1)	.307
private (z=0.2)	.3159 (26.37)	3.833 (3.79)	.394 (7.59)	.604 (9.24)	.317 (5.9)	.306
private (z=0.5)	.3181 (26.72)	3.987 (3.73)	.532 (7.03)	.614 (8.63)	.371 (5.1)	.309
private (z=0.8)	.3437 (24.32)	6.323 (2.936)	2.28 (5.99)	.696 (6.26)	.730 (3.1)	.339
priv(small)	.2275 (9.23)	40.07 (0.13)	.252 (5.56)	.540 (4.80)	.236 (4.66)	.227
priv(large)	.3211 (16.98)	100.03 (0.08)	.337 (17.90)	.619 (6.01)	.280 (3.27)	.320
public	.1878 (4.10)	3.557 (1.48)	.141 (3.26)	.567 (2.16)	.157 (2.1)	.181
cooperative	.0744 (0.55)	0.309 (0.03)	.328 (4.52)	.575 (5.15)	.328 (4.0)	.022

Table 12
Estimates of inefficiency

type of ownership	E(u)	E(u)/r	E-lnr	Total cost inefficiency
private (z=0.0)	.244	.233	.0413	.2743
private (z=0.2)	.243	.233	.0427	.2757
private (z=0.5)	.245	.236	.0400	.2760
private (z=0.8)	.269	.264	.0644	.3284
private (small plants)	.181	.158	.0441	.2018
private (large plants)	.254	.315	.0405	.3560
public	.144	.129	.0430	.1720
cooperative	.017	.015	.0280	.0430

Our results indicate measures of technical inefficiency, for full sample of private plants, E(u), ranging from 24.4% to 26.9% depending on the value of the regulatory constraint; and, therefore, the internal price of capital. Using the formula for computing cost of mean inefficiency, E(u)/r (Schmidt and Lovell, 1979, p.355), it ranges from 23.3% to 26.42%. Measures of allocative inefficiency, E-lnr, where $E = c/r*e_3 + b/r*e_2 + \ln a + c*\exp(-e_3) + b*\exp(-e_2)$ and lnr is the logarithmic value of estimated returns to scale (Schmidt and Lovell, 1979, p. 356), ranged from 4.00% to 6.44%. Mean technical inefficiency is 18.1% and 25.4% for small and large private plants, respectively. Public utilities were found to have mean technical inefficiency of 14.4% and mean allocative inefficiency of 4.3%. Cooperatives had a 1.7% mean technical inefficiency and a 2.8% mean allocative inefficiency.

The only estimation of technical and allocative inefficiencies using private electric utilities comes from Schmidt and Lovell (1979). Estimating a system of equations similar to the system presented in eq.(5.6) they report a mean value for E- lnr = .081 which indicates that allocative inefficiency raises cost by 8.1%. They show a mean cost technical inefficiency of 8.4% for a total cost inefficiency of 16.5%.

Residuals from the cost minimization equations (eq. 5.6), e_2 and e_3, can be observed for each observation. They measure allocative inefficiency for the capital/fuel (K/F) and capital/labor (K/L) ratios, respectively.

Table 13
Estimates of residuals of F.O.C., from e_2 and e_3 from the system of equations

		private (value of z)				public	co-op
		0.0	0.2	0.5	0.8		
e_3 of K/L	(mean)	.038	.082	.043	.509	-.013	-.033
	(var)	.304	.303	.304	.307	.141	.327
	(max)	1.661	1.70	1.66	2.13	.877	1.117
	(min)	-1.557	-1.51	-1.51	-1.55	-.814	-1.547
e_2 of K/F	(mean)	-.001	.044	.179	.477	.163	.079
	(var)	.368	.367	.367	.367	.368	.239
	(max)	1.570	1.615	1.750	2.048	.999	.792
	(min)	-1.464	-1.42	-1.28	-0.98	-1.166	-2.063

The means of the residuals of e_2 and e_3 for each ownership structure are presented in table 13, along with their variances, and maximum and minimum values across all observations. From the means of the residuals of K/F and K/L we can establish how far each ownership structure is from using inputs in the right proportion. Results from table 13 indicate that estimates of the means of e_2 and e_3 are close to zero. It shows only mild over-capitalization for capital with respect to fuel for all ownership types. For example, public utilities use a K/F which is only 16.3% higher than optimal. Private firms exhibit over-capitalization with respect to labor also. Moreover, public and cooperative firms show over-laborization with respect to capital. These results differ slightly from Schmidt and Lovell (1979, p.360) who find higher and positive over-capitalization with respect to both fuel and labor among private firms. They obtained a capital/fuel ratio that was, on average, 73% higher than the cost minimizing ratio while the capital/labor ratio was 36% higher than the cost minimizing ratio.

The results obtained from the system of equations confirmed the position of consumer cooperatives as the most efficient ownership structures. Publicly-owned utilities come in second followed by the private regulated (small or large plants) firms which appear to be the least efficient ownership structure. Furthermore, the results indicate that most of the total cost of inefficiency is made up of technical inefficiency. With respect to private regulated firm, this is in contradiction to the general belief that inefficiency is caused by rate of return regulation. We do not find the over-capitalization with respect to other factors as is predicted by the Averch-Johnson effect.

b) Short run production function

Estimating the system of equations presented in eq. (5.9) with MLE, where K_0 is fixed and P_k is excluded, we obtained the results presented in Tables 14 and 15.

The model provides estimates for technical inefficiency as well as allocative inefficiency. Once again, private firms (full sample) show the highest level of mean technical inefficiency, 24.56%. Cooperative utilities are the most efficient firms with a mean technical inefficiency of 6.72%, as compared to 10.98% for public utilities. When the sample of private plants was divided in large and small plants, small private plants indicated a mean technical inefficiency of 5.01% while large private plants showed a mean technical inefficiency of 24.89%. Comparison of cost of mean technical inefficiency indicates that small private and cooperatives utilities have an almost identical percentage of their total cost due to technical inefficiency, that is 6.17% and 6.37% respectively.

Public utilities come behind with 10.26% of their total cost due to technical inefficiency.

Table 14
System of equations
Short run production function
(asymptotic t-ratios in parentheses)

type of ownership	constant A	capital a	fuel c	labor b	V d_1	log L (value)
private	-9.564	.1134	.860	.0807	-.126	-12.132
(150 obs.)	(-17.12)	(1.17)	(23.1)	(12.5)		
priv(small)	-10.76	-.1047	1.149	.0835	-.173	-131.55
	(-22.78)	(-5.85)	(75.1)	(12.1)	(-1.23)	
priv(large)[24]	-4.067	.2998	.3830	.4307	-.0815	-.9937
public	-10.13	.041	.961	.0781	-.0524	-39.2
(33 obs.)	(-22.46)	(1.19)	(34.7)	(5.91)	(1.23)	
cooperative	-10.08	.028	.958	.0957	-.024	-94.64
(71 obs.)	(-34.26)	(0.29)	(46.4)	(7.43)		

Table 15
System of equations
Short run production function
Estimates of Ancillary parameters
(Asymptotic t-ratios in parentheses)

type of ownership	sigma	lambda	S_{22}	s_u	E(u)	E(u)/(b+c)
private	.3072	3.862	.603	.309	.2456	.2610
	(25.8)	(4.16)	(8.36)			
priv(small)	.0688	2.262	.522	.063	.0501	.0617
	(4.07)	(1.23)	(5.24)			
priv(large)	.3132	792.0	.617	.313	.2489	.3649
public	.1419	4.228	.543	.138	.1098	.1026
	(6.36)	(0.82)	(2.67)			
cooperative	.0942	2.023	.563	.085	.0672	.0637
	(0.99)	(0.16)	(5.78)			

[24]The likelihood function did not converge because of singular Hessian.

5- Conclusion

A summary of the results obtained from the various stochastic models is presented in Table 16. Most estimated models for all organizational forms show a substantial level of inefficiency which had been expected from the analysis of the attenuation of property rights. The second conclusion is the significance of the size of plants in explaining inefficiency; almost all models estimated for small and large private plants indicated that measures of inefficiency were almost twice as high for large plants compared to small plants. As for the conclusions with respect to the most efficient type of ownership, the long run models (cost function and system of equations) indicate that cooperatives are most efficient followed by public utilities and small private utilities. However, only the difference between CO vs PU and PR appears to be significant. PU and PR do not have significant different mean inefficiency. When we consider results from the short run models (cost function and system of equations), the short run cost function indicates that PR are most efficient while the short run system of equations shows no significant differences between PR and CO.[25] Finally, all measurement of inefficiency indicate that technical inefficiency is far more important than allocative inefficiency. Private firms did not show a strong tendancy to over-capitalize with respect to other factors of production.

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[25]Results with respect to efficiency comparison of ownership structure should be limited to plants of comparable size, cooperatives, public and small private utilities. Results with respect to large plants cannot be compared to cooperatives and public plants since we have no large plants owned by cooperatives and public utilities.

Table 16
Summary of the information on efficiency from various models

	cost Inefficiency due to technical	allocative	total
1. Stochastic frontier cost function			
1.1 Long run cost function			
1.1.1 private utilities			
a) z = 0.0			17.04%
b) z = 0.2			16.77%
c) z = 0.5			16.39%
d) z = 0.8			18.83%
1.1.2 small private			11.27%
1.1.3 large private			27.25%
1.1.4 public utilities			11.60%
1.1.5 co-op utilities			6.50%
1.2 Short run cost function			
1.2.1 private utilities			11.81%
1.2.2 small private			3.43%
1.2.3 large private			13.36%
1.2.4 public utilities			?
1.2.5 co-op utilities			8.29%
2. system of equations			
2.1 Long run stochastic frontier production function			
2.1.1 private utilities			
a) z = 0.0	23.30%	4.13%	27.43%
b) z = 0.2	23.30%	4.27%	27.57%
c) z = 0.5	23.60%	4.00%	27.60%
d) z = 0.8	26.40%	6.44%	32.84%
2.1.2 small private	15.77%	4.41%	20.18%
2.1.3 large private	31.55%	4.05%	35.60%
2.1.4 public utilities	12.90%	4.30%	17.20%
2.1.5 co-op utilities	1.50%	2.80%	4.30%
2.2 Short run stochastic frontier production function			
2.2.1 private utilities	26.10%		
2.2.2 small private	6.17%		
2.2.3 large private	36.49%		
2.2.4 public utilities	10.26%		
2.2.5 co-op utilities	5.37%		

SIXTH CHAPTER

CONCLUSION

This research aims at testing the effects of ownership structure on efficiency of various organizational forms: privately-owned regulated electric utilities (PR), publicly-owned electric utilities (PU) and consumer-owned cooperative electric utilities (CO). A comparison of those organizational forms has been conducted on the basis of (1) their structure of property rights, (2) their structure of incentives, and (3) their structure of enforcement of those rights. Property rights are defined with respect to their exclusivity, appropriability, and transferability.

The structure of property rights of PR has been shown to be attenuated because of separation of ownership from control, and because of regulation. The incentives of the principals, the stock holders and the consumers, are affected mostly because of attenuation of appropriability and transferability. After rate of regulation is effective, stock holders have no further incentives to further specialize as monitors. Consumers expect reduce prices from improved efficiency but they can appropriate further gains from improved efficiency only proportionally to their level of transaction with PR. Furthermore, they have no claim over future improvements of PR. They are expected to behave as free riders and supply less than optimal monitoring activities. Furthermore, neither the financial market nor the managerial labor market are expected to produce optimal level of monitoring. Politicians are not expected to monitor PR efficiently since they are elected every four years and over many issues. Voters

are expected to shirk their task of being properly informed on preferences of politicians as well as on their records with respect to efficiency of electric utilities. The regulatory commission has to account for consumers as well as stock holders. It is believed that it accepts the costs given by managers of electric utilities and add to it the appropriate cost of capital. They have to arbitrate among various goals, and are subject to lobby on the part of the industry.

The property rights structure of PU is attenuated because of separation of ownership from control, and because the ownership is inherited through residency. Appropriability is limited because residents have access to increased efficiency only proportionally to their level of transaction with the PU. They have no claim over expected future improvement of the team of production. Transferability is limited since residents have no individual claims over the assets of the plants. The incentives of the principals, the consumers who are residents, are further attenuated because of the free rider problem as for consumers of PR. As for PR, the political market is not expected to produce optimal level of monitoring with respect to efficiency of PU.

All aspects of property rights of CO are also attenuated. Appropriability is limited to the level of transaction of each members with the CO and by the impossibility of capitalizing expected future residuals into present value of the asset of the co-op. However, members hold partial claims over the assets of the CO. Transferability of those claims is limited since there is no financial market to trade them. Members can sell them back to the co-op. Monitoring

activities will be performed mostly by the board of directors elected by the members every year over a single issue: the efficiency of CO. Even though members of CO are expected to be more committed to their co-op than consumers with respect to PR and PU, they are still expected to suffer from the free rider problem. However, the level of monitoring of CO is likely to be strongly influenced by the Rural Electrification Administration (REA) who finances almost entirely the operations of the rural electrical cooperatives. CO have to submit financial data and other statistics to the REA each month.

Because of the attenuation of the structure of property rights for all three organizational forms, we can predict that they will show some degree of inefficiency. As for the comparison of efficiency between ownership structures, even though we cannot claim to rigourously proove the superiority of property rights of CO over PR and PU, the structure of incentives and control of CO seems superior because of (1) a more direct link with management (homogeneity of interest), (2) a more individual ownership claim over the assets, (3) a simpler political market, (4) the incentives and control structure of REA. The comparison of PR and PU is even more difficult, therefore, we should expect that their measures of efficiency will be closely related to each other.

Few research dealing with this issue with respect to electric utilities are available. Most of them have tested for efficiency comparison using a dummy variable model. Such model shows serious limitations since the concept of average function, which is used in the dummy variable model, does not represent the most efficient technology. The dummy variable measures a combination of random

shocks, technical and allocative inefficiencies, and is not capable of discriminating among them. No absolute measures of technical and allocative inefficiencies can be obtained from such model. An other research using a non-frontier estimation technique attempts to compare efficiency of public and private electric utilities, but such methodology is limited since no measure of technical efficiency is obtained. Furthermore, it is plagued with contradictions and does not fully account for technology differences among ownership types. Therefore, little is known on the issue under investigation in this research, and much remains to be done.

The choice of an appropriate methodology is crucial to conduct a comparative analysis of efficiency differences between organizational forms. Several models are available to measure efficiency of firms: (1) deterministic non parametric model, (2) deterministic parametric model, (3) deterministic statistical frontier model, (4) stochastic frontier model, (5) non frontier efficiency models, (6) total factor productivity model, (7) dummy variable model. The stochastic frontier model has been selected. When compared to other models the stochastic frontier model offers several advantages:

(a) it allows an unlimited number of observations to be technically efficient,

(b) it is not sensitive to outliers,

(c) random shocks, statistical noise, and measurement errors are not confused with measurement of technical efficiency,

(d) the stochastic frontier model permits measurement of technical and allocative efficiency separately, and these estimates have testable, statistical properties,

(e) the concept of stochastic frontier represents the theorical concept of most efficient technology,

(f) it solves the bounded range problem of the deterministic statistical model.

The weaknesses of the stochastic frontier model are:

(a) it is limited in the selection of functional form since the production function must be homothetic,

(b) it has no *a priori* good argument to select a distribution for the disturbance term.

The essential idea behind the stochastic frontier model is that the error term is composed of two parts: a symmetric component that permits random variation of the frontier across firms, and captures the effect of measurement error, other statistical noise, and random shocks outside the control of the firm; and a one-sided component which captures the effect of inefficiency relative to the stochastic frontier. This is represented by $y=f(x)-(u+v)$ where v is the symmetric component and u the one-sided component, $u>0$, and represents the absolute measure of technical inefficiency. Measures of allocative efficiency can be obtained from the residual of the first order conditions from cost minimization.

After choosing the stochastic frontier model to measure efficiency, we need to select a proper functional form; for this research we have selected a Cobb-Douglas function. The estimation of a stochastic frontier Cobb-Douglas function (production and/or cost) provides all the required information to measure, and therefore compare among various organizational forms, absolute technical and allocative inefficiencies. Moreover, it does not create critical distortions in

the estimated results of technical and allocative efficiencies. Finally, a Cobb-Douglas function captures the critical characteristics of the technology of electricity generation.

The complete model requires that we select a proper objective function to characterize the behavior of the firm. This is an important task since measurement of inefficiencies depends on a standard of comparison which is derived from our behavioral hypotheses with regard to each ownership structure. In the electric utilities, the literature strongly suggests that output and the prices it pays for inputs are exogenous to the firm. Therefore, electric utilities are expected to behave as cost minimizers. The arguments presented to justify cost minimization for private utilities can apply to public as well as cooperative utilities.

From the stochastic frontier Cobb-Douglas production function and the objective function of cost minimization, we can derive the models to be estimated: (1) a stochastic frontier C-D long run cost function, (2) a stochastic frontier C-D short run cost function, (3) a system of equations comprised of a stochastic frontier C-D long run production function and the first order conditions derived from the cost minimizing Lagrangian, (4) a system of equations comprised of a stochastic frontier C-D short run production function and the first order conditions derived from the cost minimizing Lagrangian. The estimation of those models is done through MLE using numerical techniques and Davidon-Fletcher-Powell. The ML estimation requires a proper likelihood function which is derived from an hypothesis with respect to the density function of u, v and e_i (residuals from the first order conditions).

Those models have been estimated using data from the steam electric generation in the U.S.. This industry shows interesting characteristics: (1) three different ownership structures are generating electricity using the same technology; (2) standardized data for all three types of firms are available; (3) technology of steam-electric utilities has been studied for over 25 years. The data are measured at the plant level, and are from the first full year of operation through the fifth year.

Results from the estimation of the models presented earlier indicate that:

(a) all three types of ownership structures suffer from some degree of inefficiencies,

(b) estimations of long run models (cost function and system of equations) rank cooperative utilities as the most efficient ownership structure; the difference between CO vs PR and PU is important and statistically significant. Moreover, measures of inefficiencies of PU and PR are not significantly different.

(c) estimations of short run models (cost function and system of equations) produce ambiguous results; the stochastic frontier short run cost function puts the PR as the most efficient ownership structure while the system of equations shows identical inefficiency measurement for both Pr and CO. PU shows the highest level of inefficiency.

(d) total inefficiency is composed mostly of technical inefficiency. All types of firms show a small level of allocative inefficiency, including privately-owned regulated electric

utilities. Therefore, private firms did not show a strong tendancy to over-capitalize.

(e) all comparison between those three types of ownership structures have been done for comparable size of plants. When efficiency measurement is compared for small and large plants, inefficiency of large plants nearly doubles compared to inefficiency of small plants (this comparison has been done only for PR since CO and PU did not have large plants).

This research has proven to be fruitful in that it lends to further support to the hypothesis derived from the property rights theory to the effect that a specific reward system is needed to stimulate a particular productivity response. Attenuation of property rights allows further discretionary behavior on the parts of the agents against the best interests of the principals. Such discretionary behavior is translated mostly in terms of overutilization of all resources contrary to the general belief built on the Averch-Johnson effect. Our analysis of the property rights structure of PR, PU and CO had lead to the weak conclusion that CO would be expected to be more efficient than PR and PU. Even though all models do not generate such conclusion, the overall performance of CO with respect to efficiency measurement put them first followed by PR and PU which cannot be significantly distinguished.

Such results can have important policy implications since all three types of ownership structures are the results of direct government interventions: (1) regulation of private utilities, (2) direct investment of government in the electric utility industry, (3) rural electrification program supervised by REA. It would appear that

both programs of regulation and direct investment produce similar results in terms of inefficiency. From a policy point of view, it is therefore difficult to recommand one over the other. However, the rural electrification appears to have been a success from the efficiency point of view. Regulators have been more concerned with proper level of price of capital over the years, but our results strongly suggest that they should be much more concerned with technical inefficiency than allocative inefficiency. That conclusion implies a different philosophy with respect to regulation and should lead to further investigations. Finally, the strong efficiency difference between small and large plants (nearly twice as much for large plants) should be a major concern for regulators.

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DOCTORAL EXAMINATION AND DISSERTATION REPORT

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