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Do Size and Ownership Matter for the Economic Efficiency of Electric Utilities? Canadian Evidence from Newfoundland and Labrador

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ABSTRACT

This paper investigates differences in cost structure between large public, small public, and small private electric utilities in Newfoundland and Labrador, Canada. The objective is to examine whether scale and ownership structure matter for productive efficiency. We use estimated share equations from translog cost functions to calculate elasticities of input demand and substitution, technical change, scale economies, and perform a goodness-of-fit 'test' of economic efficiency. Much of the evidence in the literature favour private ownership on efficiency grounds. In the case of Newfoundland and Labrador, this study does not. We offer several plausible explanations for this finding that generalize beyond this sample.

JEL Classification: L94, D24
Key Words: Electricity, ownership, scale, efficiency index

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INTRODUCTION

It is a truism to say that governments have long deemed control over energy to be too important to be left to markets. Captivated by the expected scale economies of ever larger power plants located at great distance from markets, and accepting that integrated power systems must be regulated, governments have often tolerated production, transmission and distribution inefficiencies and the environmental degradation that many power developments have left in their wake. However, in recent years the ownership-efficiency nexus has attracted renewed and growing public interest and in many jurisdictions, governments are extricating themselves from the business of running natural monopolies in the energy sector. There are several reasons for this. First, there is the claim that 'unbundling' generation, transmission and distribution in large vertically integrated monopolies, reducing regulation and creating a competitive electricity trading environment will combine to lower prices to end-users without compromising availability and reliability. But does privatization or deregulation actually lead to improved efficiency? The empirical literature is not unequivocal on this point. In particular, the quest for efficiency gains by means of privatization or deregulation has failed to establish conclusive evidence relating productive efficiency to the structure of ownership. Most of the theoretical and empirical literature, on electric utilities at least, has examined the narrower issue of whether private ownership *leads* to higher efficiency than state ownership. The latter issue is really only a subset of the former (Villalonga, 2000). According to this view, the broader question involves a political, organizational and economic transition phase to a modified *modus operandi*. Most of the pertinent existing literature, the present study included, have focused on differences in the *modus operandi* under different management scenarios, rather than on the transition itself. The distinction has gained currency as it stresses the unsurprising fact that in the political process, factors other than economic efficiency typically dominate public policy outcomes.

Second, a pressing reason for public concern about electric utility ownership issues stems from the growing demand for energy, and the competitive forces set in motion in recent years by the United States Federal Energy Commission that drive a sweeping restructuring of the electricity industry across North America.[1] In Europe, countries are moving toward deregulation at variable speeds. At present, only Great Britain, Germany and Sweden have completely deregulated energy markets. This trend has

[1] The trend toward a more competitive, deregulated electricity market was pioneered in Europe, notably England, Wales, and Norway. See e.g. Green (1999) and Klitgaard and Reddy (2000). By the end of the 1990s this was the practice also in about 50 percent of the U.S. states.

implications for public policy also in Canada since access to the emerging national and international electricity trading environment is undermining old captive utility markets and regulatory structures, forcing provincial governments to comprehensively review existing energy policies, including deregulation or possible privatization of public electric utilities.[2] But in the face of the recent Californian experience, deregulation and privatization may be losing some of its allure, in some Canadian jurisdictions at least, as means to improve the efficiency of the electric utility industry. Having in recent years encountered strong public opposition to privatization of a major publicly-owned utility, the Government of Newfoundland and Labrador appears to have abandoned the privatization option and is now concluding a public consultation process regarding a proposed long term plan to ensure an adequate supply of competitively priced energy using other means. The Province of Ontario plans to unveil its own energy plan in 2006. Some of the common core issues concern the type of generation capacity to be used, how it should be regulated, and whether private industry should be invited to build and operate this new capacity (Department of Natural Resources, 2005).

Third, the emergence of cleaner and more reliable micro power alternatives to grid power is creating a certain fragmentation of the electric power industry, as well as tension amongst various interest groups on account of the perceived environmental impacts associated with micro-scale hydro developments, windmills, and the harvesting and burning of bio-fuels. In this process, the ownership-efficiency issue remains a focal point of public policy as electricity generated from hydro and nuclear sources in particular form a bridge to a greener future. Since the marginal cost of operating existing such power plants can be very low, these sources can continue to produce power until the end of their useful lives unless tightened environmental standards make this unacceptable.

Fourth, decisions about the structure of the industry have implications for the feasibility of modified regulatory regimes, pricing, future supply systems, and even the use of electricity as a tool for regional economic development. Yet, the use of discounted electricity for this latter purpose seems to be in decline due to full utilization of lower cost energy supplies, trade agreements banning subsidies, and a general trend toward market liberalization.

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[2] As anticipated by Snelson International Energy (1996), some Canadian provinces have moved toward a competitive and privatized electricity market. But this move has been slow, partly because of the unique mix of crown-owned and investor-owned utilities in Canada. Alberta and Ontario have taken action to restructure their electricity industries. New Brunswick and British Columbia have begun unbundling in public utilities. Hydro-Québec has already done so. Nova Scotia Power was privatized in 1992. The other Canadian provinces have not yet made any major changes to the structure of the electrical sectors (Department of Natural Resources, 2005).

The present study extends earlier work by Wernerheim and Nadarajah (1998) to a comparative analysis of the size-ownership-efficiency nexus in three segments of the electric utility industry in Newfoundland and Labrador; 'large-scale public utilities', 'small-scale public utilities', and 'small-scale private utilities.' We specify and estimate the effect of size/ownership on the relative economic efficiency in each of these industry categories separately. A well established approach is employed involving the share equations of three- and four-input translog cost functions to calculate a relative efficiency index, and to estimate returns to scale, technical change, and own- and cross-partial elasticities of input demand and substitution.[3] Segmented corporate data for some public utilities made available by Newfoundland and Labrador Hydro[4] (NLH), and data published by Statistics Canada allow us to improve substantially upon previous estimates, although some data issues remain, as discussed below.

The analysis follows standard practice, assuming that the primary long-term objective of public policy toward the electric utility industry is economic efficiency. The objective is to examine whether, and in what direction, scale and ownership affect productive efficiency in the three utility categories identified. As such, ours is an indirect approach to the vexing question of whether private (investor-owned) electric utilities are more efficient than their public-sector counterparts. This paper does not address regulatory and marketing issues, investment financing aspects, or royalty regimes. The only dimension of economic efficiency that concerns us here is the cost of supplying electricity as manifested in differences in production structure across the three utility categories. Even if factors other than cost minimization are relevant to policy-making as previously suggested, we believe that knowledge about the efficiency of the different utility segments can usefully inform the public debate. The remainder of the paper is organized as follows. Section two discusses the related studies. Section three sets out the structure of the electricity industry and the policy context in which we frame our analysis. Section four introduces the model and the measure of efficiency. Section five discusses the data and estimation procedure. Section six presents the empirical results. Section seven concludes.

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[3] Most earlier studies have focussed on the effects of ownership structure on productivity and technical progress, and concern fossil-fuelled steam-electric generation either by investor-owned utilities or public utilities in the United States. More recent work has been based on flexible functional forms and frontier cost function specifications (see e.g. Färe et al. 1985; Nelson 1990a; Scully 1998; and Diewert and Nakamura 1999).

[4] NLH is the Province's largest crown corporation, and Canada's fourth largest utility.

1. RELATED STUDIES

Why might ownership and scale matter from the standpoint of economic efficiency of electric utilities? The literature that bears on this issue in one way or another is extensive. It has been surveyed by Vining and Boardman (1992) and others cited below. This is not the place to attempt an updating of these comprehensive accounts. In the interest of brevity, we limit ourselves to citing the results of those empirical, primarily North American, studies spanning the last forty years or so that have focused specifically on the relative efficiency of private versus public electric utility ownership. In their review of more than 90 comparative ownership studies of a wide variety of industries, Vining and Boardman (1992) conclude that ownership matters for both technical and allocative efficiency. They find that on balance, the evidence favours private ownership on efficiency grounds. Our review of the evidence for the electric industry is far less conclusive (Table 1).

Table 1. Empirical results on relative efficiency of public and private electric utilities

Public utility more efficient	No difference/ambiguous	Private utility more efficient[a]
Meyer (1975)	Shepherd (1966)	Moore (1970)
Neuberg (1977)	Mann (1970)	Wallace and Junk (1970)
Primeaux (1977)	Yunker (1975)	Peltzman (1971)
Pescatrice & Trapani (1980)	Spann (1977)	Tilton (1973)
Färe *et al.* (1985)	Dilorenzo & Robinson (1982)	De Alessi (1974a), (1975), (1977)
Côte (1989)	Edison Electric Inst(1985)	Pollitt (1994), (1995)
Koh *et al.* (1996)	Atkinson & Halvorsen (1986)	Foreman-Peck and Waterson (1985)
Kwoka (1996)	Homes (1990)	Kumbhakar and Hjalmarsson (1998)
Wernerheim and Nadarajah (1998)	Hjalmarsson and Veiderpass (1991)	Scully (1998)
	Kwoka (2005)	

Notes:
a/ See also Mann and Mikesell (1971); De Alessi (1974b); Nelson (1990a); and Newbery (1997)

On the one hand, private ownership in a un- or deregulated environment should theoretically attain superior results to public ownership as private owners can influence managers by divesting ownership shares. This does not apply to publicly owned utilities, and moreover, such utilities may be subject to manipulation for political reasons that may promote inefficient subsidies, over-employment, or other preferential treatment of constituents. Management does not have to be efficient because cost recovery is ensured through cost-based rates.[5] On the other hand, while regulators do not have full information about private sector costs, the overseer of the publicly owned utility has full information. Assuming that both the regulator and the public owner seek to satisfy the public interest, one might perhaps expect that publicly-owned enterprises outperform the privately-owned one because of access to managerial information (Kwoka, 1996). Another possibility rests on the 'no difference in efficiency' argument. According to Vining and Boardman (1992) there are two ways of reaching the conclusion that ownership does not matter for allocative efficiency. The first is to argue, as does Whitehead, (1989:9) that "there is no inherent reason why enterprises in private ownership should operate more efficiently than those in public ownership." This argument assumes no difference in the production of socio-political output (produced in addition to 'core' output.) But as the authors point out, this is contradicted by the proponents' view of public utilities as a policy tool. The second argument is that public utilities are technically and allocatively efficient but produce socio-political output, which is not taken into account in standard efficiency studies. The problem with this argument is that the extent to which public utilities raise employment, wages, and produce other socio-political output necessarily comes at the expense of profitability. In the case of Newfoundland, this study does not find support for the hypothesis that the economic efficiency of private electric utilities is superior to that of public utilities. Several plausible explanations for this finding are offered.

2. INDUSTRY STRUCTURE AND POLICY CONTEXT

Canada's electric power industry consists of provincial Crown corporations, investor-owned utilities, municipal distribution utilities, industrial generators, and so-called non-utility generators. Yet, almost all aspects of the industry are under the authority of provincial governments. In most provinces, the industry is highly vertically integrated with generation, transmission and distribution provided by a few dominant utilities. Interconnections exist between provinces, and between provinces and the United States, but they are generally small relative to the capacity of the industry in each province. The exceptions are the individual generating plants (such as Churchill Falls, Labrador) built to export power (Department of Mines and Energy, 2002).

[5] In Newfoundland, both public and private utilities are regulated this way as discussed below.

Turning to Newfoundland and Labrador, the Province has three principal electrical systems: the Island Interconnected System; the Labrador Interconnected System; and a diesel generator service to isolated areas in Labrador and on the Island. These systems are operated by two regulated utilities, NLH and Newfoundland Power (NP). NLH is a Provincial Crown corporation[6] with the mandate to generate and transmit electricity in the Province and to provide distribution and retail services to customers in Labrador and in areas of the Island not serviced by NP, an investor-owned utility.[7] NLH owns and operates approximately 80 per cent of the generating capacity on the Island. This includes 900 Megawatts (MW) of hydroelectric power and an oil-fired thermal plant (490 MW), which is used on a seasonal pattern according to rainfall.

On the Island System, NP is the primary retailer of electricity, supplying about 85 percent of electricity customers. It purchases about 92 percent of its supply from NLH and generates the balance itself from smaller hydro generating facilities. Although NLH is primarily a wholesaler of electricity, it also sells power to five large industrial customers (four on the Island[8] and one in Labrador[9]), to rural retail customers on the Island not serviced by NP, and to diesel-serviced customers in isolated communities. On the Labrador System, power is generated by Churchill Falls (Labrador) Corporation (CF(L) Co) from which the Province is entitled to 300 MW, which NLH purchases to supply customers in Labrador. Any unused portion of this power is resold (exported) to Hydro-Québec under the current Recall Sales Agreement (Department of Natural Resources, 2005).

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[6] NLH is the parent company of a group that includes Churchill Falls (Labrador) Corporation (CFLCo). NLH owns 65.8 percent of this Corporation, and Hydro Québec owns the remaining 34.2 percent. CFLCo owns and operates the 5428 MW Churchill Falls plant. The Twin Falls Power Company (TwinCo) owns 225 MW of output as compensation for the diversion of water into Churchill Falls from TwinCo's original plant at Twin Falls which is mothballed. This power is used by Iron Ore Company of Canada (IOCC) and Wabush Mines, which own TwinCo together with NLH (Department of Mines and Energy, 2002).

[7] NP is a subsidiary of Fortis Inc, which also owns Maritime Electric, the principal supplier of electricity on Prince Edward Island, a 50 per cent interest in Canadian Niagara Power Company, which distributes electricity to Fort Erie, Ontario and through interconnection, supplies the city of Cornwall, Ontario and New York's upstate system. Fortis also has investment in one US generator, and two utilities in Latin America.

[8] Abitibi-Consolidated, Corner Brook Pulp and Paper Co. and North Atlantic Refining. The paper mills also generate electricity themselves, as do three "non-utility generators" with small hydro and wind plants.

[9] Iron Ore Company of Canada (IOCC) is supplied under a separate contract with the Twin Falls Power Corporation, which has its own entitlement from CF(L) Co. IOCC also buys additional power from NLH.

In 2004, Newfoundland and Labrador had a total of 7,427 MW of electrical generating capacity of which 90 percent is hydroelectric (Table 2). The Island's share was 1,925 MW with about 65 percent in the form of hydroelectricity. Almost 96 percent of the provincial supply comes from hydroelectric sources. The total provincial electrical energy consumption (demand) was about eleven terrawatt hours (TWh) with about three-quarters on the Island and the remainder in Labrador. The hydroelectricity share of total end-use energy demand across user groups ranges from zero percent (transportation) to 67 percent (residential). The balance is made up of petroleum products and coal & coke.

Table 2. Newfoundland and Labrador installed operational generating capacity[a], and electricity demand & supply[b], 2004

	Capacity	Supply			Demand	
All systems:	MW		M kW[c]	%		M kW[c]
Hydro	6,682		39,595	95.6		
Thermal	745		1,792	4.3		
Wind	<1		<1	0		
Total capacity	7,427	Prov. supply:	41,387		Prov. consumption[d]:	11,039
minus exports[e]:	4,903	plus imports[f]:	16	0.04	plus exports[g]:	30,363
Available Prov. cap	2,524	Total supply	41,403	100	Total demand	41,402

Notes:

a/ Excludes the 225 MW of generating capacity at the Twin Falls hydroelectric facility in Labrador which has not operated since the water was diverted to Churchill Falls. Excludes the isolated hydroelectric generating capacity at Menihek in Labrador.

b/ some numbers do not sum due to rounding errors.

c/ million Kilowatts

d/ includes end-use electricity consumption and related system and transmission losses.

e/ CF(L)Co owns and operates the 5,428 MW hydroelectric generating facility at Churchill Falls and related transmission in Labrador. The majority of Churchill Falls electrical capacity is committed under long-term export contract to Hydro-Québec. A total of 525 MW are available for domestic use on the Labrador interconnected system of which 225 MW are committed to Twin Falls for the mining operations in Labrador West and 300 MW for the Labrador interconnected system.

f/ Labrador Straits Region

g/ exports to Quebec and associated system and transmission losses

Sources: Newfoundland and Labrador Hydro; and Department of Natural Resources (2005)

It is a looming electricity shortage that is the 'prime mover' behind the electricity proposals in the Provincial Government's recent Energy Plan. Growth in the Island's electricity supply is expected to run just under one percent per annum in the medium term. At this rate, existing capacity can supply Island needs until at least 2009. By 2012, it is anticipated that *Voisey's*

Bay Nickel will begin operating a full-scale hydromet plant on the Island, which alone will result in a significant rise in overall demand. This creates a need to plan for faster generating capacity expansion. The type, scale and ownership of any *new* capacity are some of key issues to be determined, and about which the public is currently consulted (Department of Natural Resources, 2005).

The electricity industry in the Province faces several challenges that relate directly or indirectly to productive efficiency, scale and ownership. They include the high cost of fuel for thermal generation, the high cost of developing new and alternative generating sources and new transmission infrastructure, as well as the direct and indirect costs of meeting increasingly more stringent environmental protection requirements. Preparation must also be made for further integration of the industry with the North American system in the future, and adaptation to the quickly changing North American electricity sector (Department of Natural Resources, 2005).

Interestingly, it has been noted at least twice previously that the present industry structure is inherently inefficient (see Table 3 for the utilities included in this study). Reasons given are the duplication of services, and extra cost in servicing boundary areas. To rectify this, the 1973 Report of the Study Group on Energy to the Provincial Planning Task Force recommended merger of the various investor owned utilities/distribution companies on the Island. A subsequent analysis by NLH of the 1989-91 offers by Fortis Ltd to acquire some of NLH's transmission and distribution assets concluded that the acquisition of NLH's distribution areas and assets would achieve efficiencies by reducing annual operating costs by about $5.4 million.

While all the earlier distribution companies now form part of NP, NLH retains a patchwork of areas where it provides distribution service. 'The fragmented nature of this territory is widely considered to be part of the reason why NLH does not recover the cost of servicing these customers when they pay the same rates which are charged to NP customers, based on NP's cost of service' (Department of Mines and Energy, 2002). Perhaps in response to these findings, government policy since 1989 has been that NLH should avail of the private sector for power generation when the cost of doing so is less than if NLH itself were to install additional plants.

Government policy has also attempted to make better use of provincial hydro electric resources. The total provincial electricity supply in 2004 was 41,400 Gigawatt hours (Gwh). But 72 percent of it was exported from the Churchill Falls Labrador facility to Hydro-Québec under a long-term (1969-2041) fixed-price contract. Regrettably for Newfoundland, there are no provisions in the contract for inflation or increasing operating costs. Repeated failures to renegotiate this deal coupled with the effects of deregulation elsewhere, and greater access to international energy markets, have lead to negotiations between NLH and Hydro-Québec (initiated in 1998 and on-going) about a 2,000 MW development on the Lower Churchill River. This site is held to be the least-cost hydro electric site in North America.

Table 3. Structure of the electric utilities in the study sample[a], by utility category, Newfoundland and Labrador, 1998

Utility	Utility Category	Installed capacity[b]	Plant size range[b]	No. of plants
Churchill Falls Labrador Corp	Large-scale public Hydroelectric	5,428,500	5,428,500	1
Newfoundland & Labrador Hydroelectric Corp	Small-scale public Hydroelectric & thermal[c]	1,579,020 % hydro: 60	560-628,000	11 % hydro: 55
Newfoundland Light & Power Co Ltd	Small-scare private hydroelectric	89,955	560-12,750	21

Notes:
a/ Excludes Dear Lake Power Co Ltd., Iron Ore Company of Canada, and Abitibi-Consolidated Inc.
b/ All applicable generating technologies. Nameplate ratings in kilowatts
c/ Including six hydro plants, one steam plant, and four internal combustion plants
Source: Newfoundland and Labrador Hydro, and Statistics Canada (1998b), Table 4

In considering the role of the private industry in developing new generating capacity and associated infrastructure, it is worth noting that the entire electricity industry in the Province is regulated by the *Board of Commissioners of Public Utilities* (PUB), with exception of the Churchill Falls generation, export sales, and the industry-owned generation. The PUB sets rates based on applications from utilities and evidence presented at public hearings regarding the required rate of return on capital invested. It has been recognized by Government that while this approach aims to control prices and utility profits, it provides limited long-term incentive for utilities to become more efficient or to encourage conservation (Department of Natural Resources, 2005).

3. THE MODEL AND THE MEASURE OF EFFICIENCY

Consider an electricity production process that generates an observed data set (W_{jit}, X_{jit}, Q_{it}), for $j=1,...k$ and $i=1,..,n$, where W_{jit} is the price of each of k inputs denoted X_{jit}. The subscripts i and t denote the firm (utility category) and observation respectively. Q_{it} is a (scalar) measure of output. Assume that the objective of the utilities is to minimize cost subject to the demand for electricity and the production technology. It is well-known that if the data satisfies the weak axiom of cost minimization (WACM), which is a necessary and sufficient condition, there exists a production function that would generate the observed cost minimizing decisions (Diewert and Parkan, 1985).

In reality, exact optimizing behaviour is rarely achieved. We therefore use a goodness-of-fit 'test' rather than a conventional test to investigate the characteristics of cost minimizing behaviour.[10] An assumption of nearly optimizing behaviour forms the basis for the former test, and it is just as good as one of exact optimizing behaviour since one only needs to define a reasonable deviation between the actual cost incurred $W_{jt}X_{jt}$ and the minimal costs given by the estimate of a cost function $C(W_t, Q_t, T; \hat{\beta})$ implied by some parametric production function $Q = f(X_t, T; \hat{\beta})$ describing the true technology, where T is an index of the level of technology representing the way in which feasible input combinations are affected by technological progress (multi-factor productivity), and β is a vector of parameters (Varian, 1990). We construct an efficiency index for each of the three utility categories in the vein of Afriat (1972) and Varian (1990). If there is a violation of WACM, the measure of departure from cost minimization by utility i is given by the efficiency index

$$E_{it} = 1 - W_{jt} X_{kt} \,/\, W_{jt} X_{jt}$$

where E_{it} is the percentage difference between the cost of the observed production process, and the cost of any other process. As such, it is a measure of what the cost savings would have been had the utility utilized inputs X_k (predicted) rather than X_j (actual) with factor prices W_j. That is, E_{it} is a calculation of the extent to which a utility category's actual cost differs from the minimizing level predicted by the model. If E_{it} is small (say, five percent as suggested by Varian), the utility is said to be 5-percent efficient in its production behaviour and is a nearly cost-minimizing agent.[11]

To investigate the relative productive efficiency of the utility categories, and the category-specific characteristics of cost minimizing behaviour such as elasticities of input demand and substitution, factor-bias in technical change, and scale economies require information about the predicted cost structure

[10] Conventional tests are based on exact optimizing behaviour in the sense that either the test statistics calculated from the data pass the test or not. If not, the hypothesis is rejected, and the deviation between observed and optimum choices is ignored. The reason is that although the non-zero errors may provide information about errors in optimization, they may also capture various data problems. Additionally, they include random elements unrelated to efficiency.

[11] It should be clear that the efficiency measure is conditional on the assumption that the true technology is of the particular parametric form specified by the cost function. See also Fox (1999).

and actual costs incurred. In specifying the econometric model we assume that the electric utility acts as a price-taker in all markets, attempting to satisfy the expected gross output at the lowest cost.[12] The prices and levels of output are thus treated as exogenous variables in the estimation of the unknown parameters. If the firm minimizes the cost with respect to all inputs on a convex input structure there exists a total cost function, dual to some arbitrary production function, that relates the minimum production cost to output quantity, input prices, and the state of technology.[13] The translog cost function is a continuous, twice-differentiable second-order approximation to such an arbitrary cost function (Appendix A). In terms of the translog, the actual cost C_{it} is related to the minimum cost C_{it}* as follows

$$\ln C_{it} = \ln C_{it}^{*} + v_{it}$$

where the error term v_{it} includes the cost inefficiency as well as statistical noise. Technical progress in utility category i is evaluated as

$$-\frac{\partial \ln C_{it}^{*}}{\partial t} = -(\alpha_t + \alpha_{tt} \ln T + \sum_j \alpha_{jt} \ln W_{jit} + \alpha_{qt} \ln Q_{it}) \qquad (2)$$

This specification represents the rate of technical progress (regress) by positive (negative) values of the L.H.S, which in turn measures reductions in cost over time in percentage terms (Kumbhakar, 1997.) Pure technical change is reflected by the α_t and α_{tt} terms, and the scale augmenting technical change is embodied in the α_{qt} . The non-neutral technical change is captured by the α_{jt} terms.[14] Specifically, the factor bias of technical change is manifested in

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[12] See e.g., Christensen and Greene (1976); Kumbhakar (1997); and Hisnanick and Kymn (1999). The non-econometric evidence surveyed by De Alessi (1974a) suggests that private and public utilities behave differently. (See also Teeples et al.1986). But indications to the contrary come from extensive testing of the Averch-Johnson overcapitalization hypothesis, which implies that the internal transfer price of capital to the generating plant is less than the external cost of capital to the firm. Joskow and Noll (1981) review the evidence for the electric industry and do not find unambiguous support for this hypothesis. For a different view, see Courville (1974). Cf. Spann (1974), and Murphy and Soyster (1983). The development of electricity establishments may include features not procured at least cost, causing a discrepancy between financial cost and true economic opportunity cost.

[13] Cost minimization does not require that the utilities know their demand curve. The procedure is also invariant to the degree of competition in the output market. We are concerned with both investment and operating decisions: assuming that an appropriate mix of base-load, cycling and peak-load capacity is installed, and that the equipment is operated to optimize system stability and reliability. This ensures that the facilities themselves will have been built at minimum cost.

[14] The α_{jt} represents the bias of technical change with respect to the jth factor since $\alpha_{jt}=\partial S_{jit}/\partial lnT=\partial^2 lnC_{it}/\partial lnW_{jit}\partial lnT=\partial^2 lnC_{it}/\partial lnT\partial lnW_{jit}=\alpha_{tj}$.

the movement of cost shares over time. Technical change is 'biased' if it alters the equilibrium factor shares holding factor prices constant (i.e., $\alpha_{jt} \neq 0$). The technology exhibits 'factor-using' bias if $\alpha_{jt}>0$, and analogously 'factor-saving' bias if $\alpha_{jt}<0$. It follows that if technical change involving the jth factor is factor-using (saving), an increase (decrease) in W_j will reduce (increase) technical change. This implies that neutral technical change increases the productivity with which all factors are used, whereas biased technical change increases the average productivity of some factor more than others.

Next, since returns to scale are defined by the shape of the average cost curve, a natural measure of the scale economies is the reciprocal of the elasticity of the cost with respect to output. Using the dual cost function (A1) admits of any degree of return to scale in production, and we estimate the returns to scale as

$$\begin{aligned} RTS_{it} &\equiv 1 - \ln C^*_{it} / \ln Q_{it} \\ &= 1 - (\alpha_q + \alpha_{qq} \ln Q_{it} + \sum_j \alpha_{jq} \ln W_{jit} + \alpha_{qt} \ln T) \end{aligned} \tag{3}$$

If the returns to scale are increasing (decreasing), the elasticity of costs with respect to output is positive (negative).[15] When returns to scale are constant, total cost and output increase at the same rate, i.e., RTS=0. The final characteristics of the cost structure considered are the Allen-Uzawa partial elasticities of substitution, and the related input own- and cross price elasticities. The Allen-Uzawa partial elasticities of substitution *(σ_{jk})* for utility category *i* calculated from the cost structure following (Binswanger 1974) are

$$\begin{aligned} \sigma_{jkt} &= (\alpha_{jkt} + S_{jt}S_{kt}) / S_{jt}S_{kt}, \ j \neq k \text{ and} \\ \sigma_{jjt} &= (\alpha_{jjt} + S^2_{jt} - S_{jt}) / S^2_{jt}. \end{aligned} \tag{4}$$

If $\sigma_{jk}>0$ ($\sigma_{jk}<0$) for $j \neq k$, then the inputs *j* and *k* are substitutes (complements) in production. If the cost function is Cobb-Douglas, then $\alpha_{jk}=0=\alpha_{jq}$ in eqn (A2). This implies in turn that $\sigma_{jk} = 1$. The related input own- and cross price elasticities are then immediate

$$\begin{aligned} \eta_{jkt} &= \sigma_{jkt} S_{jt}; \ j \neq k, \text{ and} \\ \eta_{jjt} &= \sigma_{jjt} S_{jt} \end{aligned} \tag{5}$$

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[15] When *RTS>0* (*<0*), conventional measures of total factor productivity growth overestimate (underestimate) the effects of technical change.

Intuitively, the percentage change in variable input j caused by a percentage change in the kth input price is equal to the technical substitution possibility between inputs j and k weighted by the kth variable input's share in cost. The partial substitution elasticities are symmetric by Young's theorem, unlike the input price elasticities $(\varepsilon_{jk} \neq \varepsilon_{kj})$. To test for statistical significance we hold the cost shares S_{ij} constant at their means over the sample period and obtain the asymptotic variances of the elasticities of substitution (Pindyck 1979).[16]

4. DATA ISSUES AND ESTIMATION PROCEDURE

For each of the three utility aggregations in our sample, the model comprises a set of share equations derived from a translog cost function. Each of these three models are estimated separately. The share equations give the shares of the inputs in the value of output and the rate of technical change as functions of relative prices and time. The models are estimated on annual time series data for the period 1963-98. The data come from Statistics Canada (1998a-d), Newfoundland Statistics Agency (1994), the annual reports of CF(L) Co, and the annual reports and other corporate sources within NLH. The small-scale private utility data that we use span the period 1963-97. Some private industry data dates to 1956. But inconsistencies between sources and other reporting problems, partly due to the amalgamation of these utilities in 1966 render these early data incomplete and unreliable for the present purpose. The small-scale and large-scale public utility data cover the periods 1968-98, and 1972-98 respectively. Although significant investment in what were to become the large-scale public plant (CF(L) Co) had taken place prior to 1967, commercial public utility generation did not begin until that time.[17]

The data consist of annual observations by utility category on output and up to four input aggregates; labour, capital, fuel and materials, depending on the technology mix specific to the utility category. The generation technology (i.e., input-mix) differs between our utility categories, and within, in the case of small-scale public utilities. The responsibility for transmission and distribution rests primarily with the public utilities. Unfortunately, data segmented by function were unavailable for any of the electric utilities, although the industry as a whole is regulated. While plant-specific (or technology-specific) data on factor usage exist for public and private utilities

[16] As noted by a referee, since the relevant shares are the predicted shares, using the actual shares and treating them as constants can be expected to understate the associated standard errors.

[17] For the historical aspects, see Zuker and Jenkins (1984); Baker (1990) and (1994).

alike, they are unavailable for the present purpose. According to an NLH source, accounting and record keeping practices have resulted in a certain 'pooling' of the data made available by NLH for this study. However, confidentiality concerns and changes in accounting practices over time limit both availability and comparability of relevant historical data. Similar circumstances apply to the private utilities. The upshot is that the aggregated annual time-series used in this study were the best data available (cf. Griffin, 1977; Daly and Rao,1985).

The data on labour measures the number of employees in full-time equivalents. Total employee expenses were divided by the total number employed in order to obtain an implicit price index of labour services in each of the three utility categories. To resolve the difficulty of determining the price of capital when equipment is not rented, we use variations of the 'net asset approach' employed by Daly and Rao (1985) and others. The capital stock is defined as the sum of total assets minus current liabilities. For the price of capital services, an opportunity cost of capital was calculated by dividing interest payments plus depreciation by net assets. This approach has the advantage of allowing category-specific changes in the capital stock to be reflected through the depreciation rate. The opportunity cost of capital is measured as interest payments plus depreciation in dollar terms and in percentage terms for 'small private' and 'large public' utilities respectively as a result of variations in data reporting practices. Alternative approaches to measuring the cost of capital were considered[18] but abandoned in favour of the net asset approach, which allows full use of available data in constructing measures that are consistent across utility aggregations. The fuel input is an aggregate of four types of diesel oil. An index of fuel outlay was computed using the average price of the fuel grades used. The Divisia index was used as an aggregation procedure. The prices used were the implicit prices, i.e., the average cost per unit obtained by dividing total expenditure on a particular fuel grade by total quantity consumed. Intermediate non-fuel material inputs represent operation, administration and maintenance expenses. Following Diewert and Nakamura (1999) and others, we use the implicit GNE deflator to obtain a unit measure of 'materials.' Output, finally, is measured in kilowatt-hours of net generation by electric utilities connected to the provincial power grid. The means of the cost shares by utility category and input category are shown in Table 4.

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[18] For alternative approaches, see Atkinson and Halvorsen (1980) and (1984). To estimate a restricted cost function (with capital held fixed) would be inappropriate here given the significant periodic investments.

Table 4. Cost shares[a] by utility category

Category/Share	S_K	S_L	S_M	S_F
Small-scale private	0.493 (0.063)	0.352 (0.052)	0.156 (0.067)	-
Small-scale public	0.579 (0.096)	0.129 (0.048)	-	0.168 (0.111)
Large-scale public	0.782 (0.064)	0.119 (0.036)	0.099 (0.035)	-

Notes:
a/ The shares of capital(K), labour(L), materials(M), and fuel(F) respectively are measured at the mean of the data. Standard deviations in parenthesis.

We follow the usual *ad hoc* practice (see e.g. Binswanger 1974), and assume an additive random error structure that satisfies Zellner's seemingly unrelated regression (SUR) model.[19] It is expected that the model will have auto-correlated disturbances since the rate of technical change is not directly observable. Some of the preliminary estimations yielded non-zero off-diagonal elements of the variance-covariance matrix of disturbance terms. However, attempts to correct for autocorrelation by transforming the data using a first-order autoregressive process in which *rho* was estimated with the other parameters in each of the three utility categories rendered values of *rho* not statistically different from zero. All estimations were therefore done on the original data. Chow (1960) tests indicated some evidence of structural breaks in the data at the .05 level for all utility categories. Attempts to correct for this problem failed on account of the small number of observations in each data set. We recognize that this can be expected to bias in either direction the efficiency measures used in this study.

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[19] With the cost function homogeneous of degree one in input prices the cost shares are homogeneous of degree zero and sum to unity. The error terms of the share equations thus sum to zero, rendering the variance-covariance matrix singular. The equations are therefore not independent. One arbitrarily chosen share equation must be dropped before the SUR procedure can be iterated to convergence (Berndt and Savin,1975). The parameters of the deleted equation(s) can be estimated residually by invoking the assumptions of homogeneity and symmetry. When the convergence criteria (Dryhmes 1971) are satisfied the values of the resulting estimates are asymptotically equivalent to maximum likelihood estimates. It should be noted that the estimates based on the share equations alone do not yield all the parameters of the cost function. The efficiency of the estimation may therefore improve were the cost function estimated jointly with the share equations. Unfortunately, insufficient degrees of freedom preclude this in our case.

5. RESULTS

Since there is no reason to assume *a priori* that the underlying production technology in any utility category is homothetic and homogeneous, several statistical tests were performed to select the model that best represents the structure of production of electrical utilities in each category. Judging by the R^2 and the asymptotic *t*-values for the parameters, the fit of the three models (one for each ownership/size category) vary but are generally acceptable. The category-specific estimates of cost efficiency, technical change, input demand- and substitution elasticities, and returns to scale are reported below. The key parameters are statistically significant and have the expected signs except in the cases indicated below.

Homotheticity and Homogeneity

We test first whether the cost structure is homothetic translog since this bears on the inclusion of the output variable in the share equations (Takayama, 1985:149). The estimation results for the unconstrained models (Table B1) show that for small private utilities 80 percent of the parameter estimates are significant at the conventional levels. This rate falls to 47 percent and 45 percent respectively, for large and small public utilities. In all three utility categories most of the α_{jQ} terms are significant at least at the .1 level. On the basis of these results, the null hypothesis of an underlying homothetic technology is rejected for all categories.

Technical Change and Factor Bias

All utilities except the large public show technological progress over the sample period (Table 5). The large public utilities were built to the currently installed capacity in the mid 1960s, and they continue to operate with the hydroelectric equipment installed at the time. Turning to the constituent components of technological progress, we reject Hicks neutrality for all utilities except for the small public utilities, which interestingly show negative pure technical change. The second test aims at checking whether the technological change exhibits any factor-bias (i.e., whether $\alpha_{jt} \neq 0$). The effect of the estimated bias of technical change is indicated by the sign of the α_{jt} terms. The parameters can be interpreted as changes in the value shares of each utility category with respect to time, holding prices constant. This component can be attributed to changes in technology rather than to substitutions among inputs. Only small private utilities exhibit non-neutral technical change. The factor bias (Table 5) appears to be in broad agreement with the pattern of cost shares for the three utility categories calculated on the raw data (Table 4), as well as with results reported for electric utilities elsewhere in the literature.[20] The scale augmenting technical change is zero for the large public utility only. This is as expected since the size of that facility has not changed.

Table 5. Technical change[a] by utility category

	Small-scale private	Small-scale public	Large-scale public
Technical change as the sum of:	progress	progress	zero
Pure	zero	negative	zero
Non-neutral	positive[b]	zero	zero
Scale augmenting	positive	positive	zero

Notes:
a/ estimated at mean of the data. +/- values significant at 0.05 level
b/ the factor bias is capital- and labour-saving, and material-using

Elasticities of Substitution

Unitary substitution elasticity is rejected for all utilities. The estimated substitution elasticities (Table 6) indicate pair-wise substitution possibilities between all inputs, affecting in turn the distribution of the value of the output among the inputs. The Allen-Uzawa elasticities of substitution show that K and L are substitutes in all three categories. K and M are complements in large public utilities, but substitutes elsewhere. L and M are substitutes in all public utilities, but complements elsewhere. For small public utilities F and K are complements, as are F and L, whereas F and M are substitutes.

[20] Variations in the pattern of factor bias in the literature stem, in part, from the number of inputs considered. Gollop and Roberts (1981) report K-neutral, L-saving, and F-using bias; Gollop and Roberts (1983) and Stevenson (1980) report F-using, and L and K-saving bias; Nelson (1986) report estimates for three time periods: first, K-saving, and F-using bias; second, F-using; and third, L and K-using, and F-saving bias; Jorgensen and Fraumeni (1983) report K, M and L-saving, and F-using bias; Daly and Rao (1985) report K and L-saving, and F and M-using bias. Wernerheim and Nadarajah (1998) report K and M-using bias for private utilities. Hisnanick and Kymn (1999) report F-using and K-neutral bias, and technical progress for private utilities.

Table 6. Estimated Allen-Uzawa elasticities of substitution[a] by utility category

	small-scale private	small-scale public	large-scale public
Parameter	Estimate	Estimate	Estimate
σ_{LL}	-0.04* (0.1947)	-3.1072† (1.5424)	-3.6115‡ (1.3193)
σ_{KK}	-1.1269 (0.2574)	-0.6402‡ (0.2606)	-0.0156* (0.0598)
σ_{FF}	-	24.229* (61.198)	-
σ_{MM}	25.783* (93.239)	-22.342 (18.622)	11.723‡ (30.044)
σ_{LK}	1.1147 (0.0215)	0.6812‡ (0.1755)	0.4358* (0.1964)
σ_{LF}	-	-3.7852‡ (4.8187)	-
σ_{LM}	-4.5667* (4.3456)	2.6097* (1.0724)	1.1901 (0.1816)
σ_{KF}	-	-0.1588 (1.1363)	-
σ_{KM}	0.7408‡ (0.2)	1.7656 (0.4808)	-0.7548‡ (0.883)
σ_{FM}	-	2.0686 (1.765)	-

Notes:
a/ Estimated at mean of data. Standard deviations in parenthesis.
* significant at the .01 level
‡ significant at the .05 level
† significant at the .1 level

Elasticities of Input Demand

The curvature restrictions imposed by cost-minimizing behaviour require that the Slutsky matrix of compensated price derivatives (second-order derivatives of the cost function) be negative semi-definite. It follows that a necessary (but not sufficient) condition for cost-minimization is that the diagonal terms (Table 7) be negative. That is, all (compensated) own-price elasticities ε_{ii} must be negative. The factor demand structures for the three categories all have ε_{ii} terms with the expected sign except materials for small private and large public utilities, and fuel for small public utilities. The finding for fuel can be explained in large measure by the lack of substitution possibilities in the face of volatile crude oil prices over the sample period. It may also be related to the fuel procurement practices of some electric utilities. Very substantial inventories of fuel relative to quantities annually used are often maintained. These tie up financial resources in fuels and inventory maintenance. Weak incentives for least-cost procurement have also been linked to automatic adjustment clauses although the evidence appears mixed (Joskow and Schmalensee,1983; and Zucker and Jenkins,1984:17).

The ε_{KK} term in small private utilities has the expected sign but is not significantly different from zero. If our models are in fact correctly specified, then a plausible explanation is the (implicit) assumption of negligible differences between *ex-ante* expected and *ex-post* realized prices of capital. But if expectations are not realized regarding the purchase and disposal prices of non-adjustable inputs, future interest rates, tax rates and depreciation rates, the *ex-ante* user cost can differ significantly from the *ex-post* user cost observed from accounting data (see Diewert (1991) and the references cited therein). It is thus possible that our capital cost measures do not reflect the real cost of capital employed.

Another explanation centres on a short-run/long-run distinction involving a variable that is not in our model, installed capacity. The cost of installing new generating capacity is primarily an irreversible capital cost: the cost is sunk once the capacity is installed. If one therefore concludes that the short run marginal cost is zero, then a sunk cost argument requires that all generating (and in our case transmission/distribution) capacity be utilized once installed. In reality this is not the case. Although the price of capital is sensitive to wasteful duplication of facilities, investment in capacity is essentially a function of expected future demand for electricity. Given the extreme lumpiness of investment in capacity in all industries in our sample, and given the aggregate nature of our data, capacity usage may be a better means of capturing this capital aspect. After all, further capital expenditure will depend more on the size of installed capacity and less on its price, whereas capacity usage depends on current demand. Interestingly, Daly and Rao (1985) found that their empirical results were not materially affected when capacity utilization was omitted from their cost function.[21]

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[21] A strong indication that our results would be similarly unaffected is that the proportion of electricity purchased in total operating expenses for small public and private utilities remained stable over the study period at about two percent and 65 percent respectively. No electricity was purchased by the large public utility in the sample period. However, the omission of installed capacity and/or capacity utilization constitutes a potential estimation problem that bears further testing using more data, and more detailed modelling of the investment process than available data permit us to employ.

Table 7. Estimated own- and cross-price elasticities of input demand[a] by utility category

Utility category	Input:	Labour	Capital	Fuel	Material
small-scale private	Labour	-0.0219* (0.0512)	0.5362 (0.0639)	-	-0.5143* (0.0918)
	Capital	0.4016 (0.0524)	-0.5273 (0.0628)	-	0.1256‡ (0.0691)
	Fuel	-	-	-	-
	Material	-1.6913 (1.8128)	0.3517‡ (0.0995)	-	1.3394* (1.1897)
small-scale public	Labour	-0.4264† (0.1861)	0.4013‡ (0.1439)	-0.2501‡ (0.242)	0.2752 (0.1513)
	Capital	0.0954‡ (0.0502)	-0.3466‡ (0.0836)	0.0625* (0.0981)	0.1887 (0.0899)
	Fuel	-0.441‡ (0.6521)	-0.1729* (0.795)	0.4015* (1.3502)	0.2124 (0.1284)
large-scale public	Labour	-0.4442‡ (0.1586)	0.3309* (0.1463)	-	0.1133 (0.0316)
	Capital	0.0579* (0.032)	-0.00852* (0.0479)	-	-0.0494‡ (0.025)
	Fuel	-	-	-	-
	Material	0.1362 (0.0316)	-0.6311‡ (0.7972)	-	0.4949‡ (0.8061)

Notes:

a/ Estimated at mean of data. Standard deviation in parentheses.

* significant at the .01 level

‡ significant at the .05 level

† significant at the .1 level

Returns to Scale

Calculating the returns to scale from (3) assuming an industrial structure of natural monopoly reveals some interesting differences across utility categories. Amongst small utilities, those privately owned indicate increasing returns, while public utilities appear to exhibit decreasing returns on average over the sample period (Figure 1). But the evidence suggests marked scale economies for the small public utilities in recent years, and in the early years immediately following the inception of the public utilities in the province. Large public utilities, on the other hand, exhibit increasing returns to scale on average over the sample period.[22] These results are in agreement with those of Koh et al. (1996). Testing for statistical significance, we fail to reject the null hypothesis of increasing returns to scale for large public utilities and small private utilities at the 0.01 level of significance. For small public utilities, we accept the alternative hypothesis at the same level of significance of constant returns to scale.

These results are consistent with the two existing Canadian studies of which we are aware. The first is by Daly and Rao (1985) who report scale economies for Ontario Hydro, a public utility.[23] In the second study for Newfoundland, Wernerheim and Nadarajah (1998) find scale economies for private utilities, but diseconomies of scale for the aggregate electric utility industry.[24]

By our maintained hypothesis of utilities operating on the declining portion of their respective average cost curves, we have no reason *a priori* for expecting differences between utility categories in the extent to which capital embody exploitation of scale economies. An interpretation of our results on scale economies consistent with the apparent factor-bias differences reported above is that the scale estimates reflect different patterns of learning how best to exploit scale economies. Rose and Joskow (1990), for example, show that large firms and investor-owned utilities are likely to adopt new technology earlier than their public sector counterparts.

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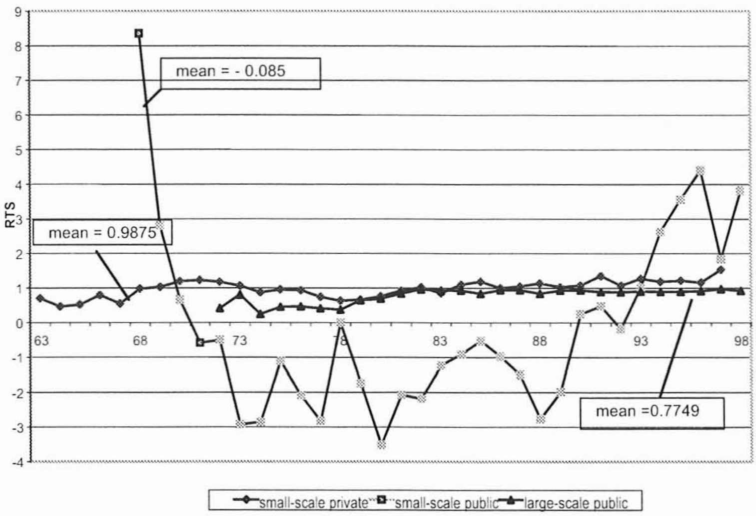
[22] These estimates are somewhat higher than most electric utility scale estimates reported in the literature. For example, Nelson (1990b) estimates the elasticity of scale with respect to output ε_{CQ} at .9431; Hisnanick and Kymn (1999) report a value of .164; Gollop and Roberts (1981) report a range: .68-.9; as do Nelson and Wohar (1983): .9274-.9672; and Neuberg (1977): .9539-.9878. Joskow (1987) reports scale economies in generation; Christensen and Greene (1976) find that most utilities in their sample exhibit scale economies, but the larger firms supplying most of the output show only minimal scale economies. Although most studies find scale economies at the plant level, it is not clear how important they are, at what level they are exhausted, or how they derive from unit- or multi-unit economies (Joskow and Schmalensee 1983). Transmission capabilities transform scale economies at the plant level into economies at the system-level, but in almost all cases, data limitations make it impossible to distinguish empirically estimates of scale economies at the generation-level from system-level economies.

[23] The size of the power plants in their sample is large by our definition. It should be noted that in highly trended time series the elasticity of scale and the rate of technical change are generally correlated, and the latter, therefore is difficult to identify unambiguously (Fuss and Waverman, 1981). Consequently, our estimates of the returns to scale may be biased downwards and upwards respectively. This bias aside, we recognize that estimating returns to scale from time series data is not entirely satisfactory for obvious reasons.

[24] The authors fail to report separate estimates for the public utilities for lack of adequate data.

Figure 1. Intertemporal Returns to scale by industry category, 1963-98



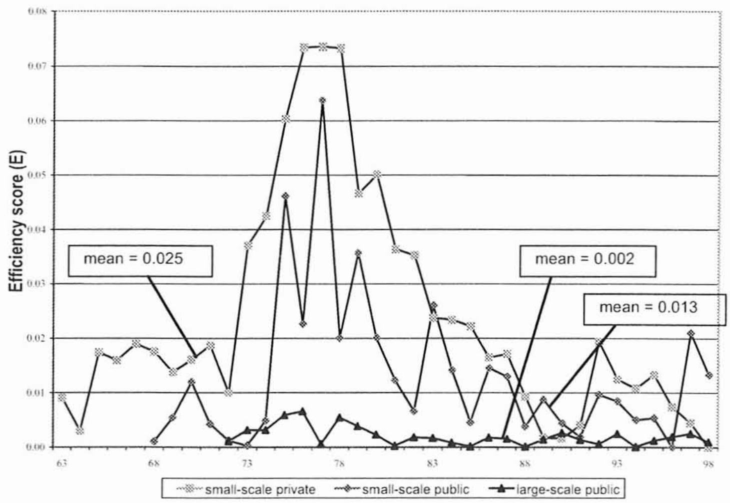
This might affect the time lag before technical change produced economies of scale, or the extent to which investment in (small) publicly-owned plants that are smaller than minimum efficient size would continue. Regarding the large publicly-owned plant in Newfoundland, it is conceivable that legal constraints on the export of electricity referred to above combine with a local market for electricity that is simply not large enough to fully exploit existing scale economies in the electricity industry.

Another explanation for the differences between utility categories observed here is suggested by the work of Kwoka (1996). Using a novel approach to attribute costs to generation versus transmission, Kwoka argues that economies of scale tend to appear horizontally at the distribution and transmission levels but not at the generation level. The fact that electricity transmission and distribution costs are borne primarily by public utilities in Newfoundland may explain why this category is also realizing the strongest scale economies.

Efficiency Score

The efficiency index (1) tracking the efficiency score by utility category over the sample period (Figure 2) suggests that the performance of large-scale public utilities ranks first, in absolute and relative terms, in the integrated system activities of generation, transmission and distribution. Small-scale public utilities rank second. Small-scale private utilities appear relatively less efficient than their publicly-owned counterparts. Small-scale private utilities rank third also in terms of the variability of their performance. The efficiency scores for the large- scale public category show a remarkable 0.2 percent mean divergence from cost minimization over the sample period. The mean cost divergence for small-scale public and small-scale private utilities is also surprisingly low: 1.3 percent and 2.4 percent respectively. Apart from a period in the late 70s and early 80s, the small-scale utilities performed well within the 5-percent limit suggested by Varian (1990) as an appropriate cut-off point. Moreover, there is an indication of increasing efficiency improvements over time, and a convergence across utility categories.

Figure 2. Intertemporal efficiency scores by industry category, 1963-98



We caution that these results should be viewed in relation to the R^2 statistics (Table B1) since the efficiency scores depend on the accuracy of the predicted cost shares. That said, these efficiency results are a possible manifestation of what Teeples et al. (1986) call the 'Alchian-Clarkson theory of public-private performance' stating that public managers, on average, may be more constrained than private managers in making decisions about input choice and the distribution of the benefits of production. But mean levels of performance may be irrelevant as pointed out by Teeples et al.: the variability within each form of ownership may be the key behavioural difference.

CONCLUSIONS

Using separate data for small-scale public, large-scale public, and small-scale private electric utilities in Newfoundland and Labrador this paper seeks to test the hypothesis that private (investor-owned) utilities are more efficient than their public sector counterparts, and that the scale of the operation matters. Using a goodness-of-fit test rather than a conventional statistical test, we do not find support for this hypothesis. In reference to the production efficiency bench-marks reported for other industries in the literature, the three utility categories in our sample all appear to be operating at very high levels of efficiency. In terms of the relative efficiency performance, the large-scale public utilities rank ahead of the small-scale public utilities, followed in turn by the small-scale private utilities. Indications of economies of scale are found for large public and small private utilities over the sample period, whereas the small public utilities seem to exhibit constant returns to scale (consistent with cost minimization in long run competitive equilibrium) on average over the sample period. The problematic methodological and data issues discussed above notwithstanding, we find that size (scale) and ownership do not seem to be critical determinants of economic efficiency for electric utilities in Newfoundland during the period 1963-1968. Whilst this may strike one as surprising, several plausible reasons may be advanced.

The first turns on differences in indirect or largely hidden subsidization of key inputs between utility categories. For example, the debt of public electric utilities is guaranteed by the provincial government, reducing the risk to lenders and lowering the cost of capital. In some cases the capital costs of public utilities may have been long forgotten. Moreover, public utilities are not required to earn an (after-tax) return on equity comparable to that in private utilities. This further reduces the cost of capital. Since public utilities are not required to pay federal income tax, and generally do not pay provincial income tax[25], the before-tax rate of return could be lower still. These factors may combine to increase the capital-intensity beyond what is required for economic efficiency. Lower rates can be charged to users, which in turn increase demand and thus possibly also the size of the public utility.[26] These aspects beg the question why a mature, well-capitalized industry such as the electricity industry should receive subsidies such as government liability insurance in the first place. This issue is broadly consistent with the reasons for inefficiencies in terms of cost recovery in the small-scale public category noted in previous studies. Although this utility category is efficient in our sense, this may help explain why this category nevertheless had a lower efficiency score than the public large-scale utilities. This would also be consistent with private utilities (also subject to regulation and similar cost recovery) ranking third in terms of relative efficiency.

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[25] In Newfoundland and Labrador the large public utilities pays no tax. The small public utilities have paid provincial and some municipal tax only since 1993, whereas the small private utilities have done so over the entire study period.

[26] It has been argued that standard cost comparison studies therefore cannot show 'true' public-private efficiency differences. For a strong defense, see Teeples et al. (1986).

Second, the geographic monopoly of most electric utilities tends to preclude direct competition in the product market. Generally speaking, where substantial scale economies, high entry barriers or externalities are present, public ownership may be preferred. In our case this argument gains more force when reversed: the large public utility is arguably enjoying its superior relative performance less on account of its ownership structure, and more on account of functions that emphasize generation over transmission and distribution (i.e., its export orientation, and favourable geographical location).

Third, as in the present study, the estimated characteristics of production and efficiency may differ by scale for the same ownership category. Utilities with lower transmission/distribution costs may thus appear more efficient than they are in fact. However, the circumstance that the private utility in our sample has lower transmission/distribution costs than its public sector counterpart does not appear to render the former more productively efficient. We venture that this is related to the very substantial proportion of electricity purchased by the private utility from the public utility. The purchase price presumably includes a charge for transmission.

Fourth, our results reflect the 'average' performance of the firms or plants that make up each utility category. There is no reason to expect *a priori* that all firms within each category perform at the same level of efficiency. This may result in an indeterminate bias of the results upwards or downwards.

Fifth, some of the differences in relative performance can be traced to limitations in the data typically used in the analysis of electric utilities. One such problem that we face is that between the form of ownership and the accounting conventions used, it is generally not possible to identify separately the cost attributable to the various interconnected functions of generation, transmission and distribution (Seth 1984: 179; and Lee 1995).[27] Moreover, the same corporate entity (whether private or public) often produces electricity using different configurations of multiple technologies (hydro, nuclear, thermal, wind, gas turbines.) The technology-specific data pertaining to generating capacity and output level can be identified, but the associated input data generally cannot. Failure to control for the factors that bear on the efficiency-scale-ownership nexus, even within a given utility category, (technology mix, output level, installed capacity, and the regulatory environment) may produce results that it would be misleading to attribute to ownership alone. Finally, the common caveat applies: structural breaks in the data, possible measurement errors in the variables, any omitted variables, and effects not controlled for may have polluted the estimates to a degree that is impossible to specify.

[27] Cf. Kwoka (1996); Gunn and Sharp (1999); and Salvanes and Tjøtta (1995).

In the final analysis, the apparent superior relative performance of publicly owned systems found in this study might lie in the ability of regulators to monitor closely managerial operations, thus providing the regulator with reliable information on the utility's operating cost and investment requirements. The effect may be to offset or mask some of the aspects of economic inefficiency referred to above. Consequently, subject to the caveats noted, we do not find compelling support for public ownership of electric utilities. The reason, and most important conclusion of this analysis, is that data problems are the most likely source of the discrepancy between the efficiency findings reported in the literature on electric utilities. This signals that great caution should be used before drawing policy conclusions regarding the 'best' ownership structure. It would be an omission not to emphasize this point.

APPENDIX A

The translog cost function can be written

$$\ln C^*_{it} = a_0 + \sum_j a_j \ln W_{jit} + a_q \ln Q_{it} + a_t T$$

$$+ \frac{1}{2}\left\{ \sum_j \sum_k \alpha_{jk} \ln W_{jit} \ln W_{kit} + \alpha_{qq} \ln Q^2_{it} + \alpha_{tt} T^2 \right\}$$

$$+ \sum_j \alpha_{jq} \ln W_{jit} \ln Q_{it} + \sum_j \alpha_{jt} \ln W_{jit} T + \alpha_{qt} \ln Q_{it} T$$

where

$$\sum\nolimits_j \alpha_j = 1,\ \sum\nolimits_j \alpha_{jk} = 0\ \forall k,\ \sum\nolimits_j \alpha_{jq} = 0,\ and \sum\nolimits_j \alpha_{jt} = 0 \qquad \text{(A1)}$$

are the necessary and sufficient conditions ensuring that $C_{it}*(\cdot)$ is homogenous of degree one in input prices.[28] The time variable denoted T captures any

[28] For the cost function to be dual to a well-behaved production function the second-order coefficients of the Hessian of the cost function must also be symmetrical (i.e., $\alpha_{jk}=\alpha_{kj}$). This reduces the number of coefficients to be estimated as they imply the restrictions set out above.

Hicks-neutral technical change. The other variables are as defined above. Symmetry requires that $\alpha_{jk} = \alpha_{kj}$.

It is well-known that the flexible functional form avoids *a priori* parameter restrictions that may bias coefficient estimates affecting factor substitution, homogeneity, homotheticity, and technical change. We impose and test the standard linear parameter restrictions in turn:

Homotheticity:	$\alpha_{jq} = 0$
Homogeneity:	$\alpha_{jq} = 0,\ \alpha_{qq} = 0$
Hick's neutrality:	$\alpha_t = \alpha_{tt} = 0$
No technological change:	$\alpha_{jt} = 0,\ \alpha_{qt} = 0,\ \alpha_t = \alpha_{tt} = 0$ for all *j, q,* and
Unitary substitution elasticity:	$\alpha_{jk} = 0,\ \alpha_{jq} = 0$

For the cost function to be well-behaved for all input price combinations it must be both monotonic and concave[29] in the input prices. That is, an increase in an input price must lead to increased total cost, and the predicted cost shares must be non-negative at each data point. By Sheppard's lemma (Diewert 1971), the corresponding cost share equations are

$$S_{jit} = \alpha_j + \sum_k \alpha_{jk} \ln W_{kit} + \alpha_{jq} \ln Q_{it} + \alpha_{jt} T \qquad \text{(A2)}$$

where $$S_{jit} \equiv \frac{\partial \ln C^*_{it}}{\partial \ln W_{jit}} = \frac{W_{jit} X_{jit}}{C^*_{it}}, \qquad \sum_j S_{ji} = 1$$

is the cost share, and where X_j is the cost-minimizing derived demand for the *j*th input obtained by differentiating C^*_{it} with respect to the price of the *j*th input. The term α_{jk} is the response of the share of *j*th input to a proportional change in the price of the *k*th input. Consequently, if $\partial S_{jit}/\partial ln W_{kit} = \alpha_{jk} > 0$ $(\alpha_{jk} < 0)$, then *i*th cost share increases (decreases) with an increase in the price of the *j*th factor. Note that the share equations (A2) allow both non-homotheticity and non-neutral technical change.

[29] Though not globally concave, this cost function is concave at the point of approximation if the Hessian matrix $[\partial^2 C/\partial W_j \partial W_k]$ is negative semi-definite; or alternatively, if the matrix of Allen-Uzawa partial elasticities of substitution (Table 6) is negative semi-definite.

APPENDIX B

Table B1. Parameter estimates by utility category[1]

Parameter	small-scale private	SE	small-scale public	SE	large-scale public	SE
α_L	101.45*	21.77	-23.012	44.97	-10.965	15.1
α_K	70.933*	13.62	-60.034‡	49.87	-23.54	24.85
α_F	-		-7.1773	58.53	-	-
α_M	-171.38*	16.81	91.224	87.14	35.505	29.54
α_T	-27,405	116,600	2,013,200.0*	1,012,000	-322,170.0*	17,754
α_Q	1,804.4	1,677	10,691.0‡	4,416	442.68‡	203.46
α_{TT}	3,942.1	15100	-263,050.0*	132,900	42,485.0*	2,208
α_{QQ}	-2.2206	3.248	13.591*	3.866	0.107	0.152
α_{QT}	-233.13	216.2	-1,425.5‡	585.8	-58.386‡	26.752
α_{LL}	0.217*	0.049	0.047†	0.035	0.045‡	0.024
α_{KL}	0.019	0.015	-0.019‡	0.01	-0.047*	0.017
α_{LF}	-		-0.045‡	0.019	-	-
α_{LM}	-0.237*	0.044	0.016	0.044	0.001	0.03
α_{KK}	-0.004	0.014	0.042‡	0.018	0.162*	0.034
α_{KF}	-		-0.0593*	0.0164	-	-
α_{KM}	-0.015‡	0.008	0.036	0.028	-0.115‡	0.042
α_{FF}	-		0.0973*	0.0343	-	-
α_{MF}	-		0.0069	0.0486	-	-
α_{MM}	0.252*	0.043	-0.059	0.089	0.114‡	0.061

Cont'd

Parameter	small-scale private	SE	small-scale public	SE	large-scale public	SE
α_{KQ}	0.047	0.038	-0.107*	0.052	0.026‡	0.012
α_{FQ}	-		0.0872†	0.0576	-	-
α_{MQ}	0.04†	0.024	0.079	0.082	-0.023†	0.015
α_{LT}	-13.142*	2.807	3.095	5.945	1.425	2
α_{KT}	-9.365*	1.742	8.063	6.619	3.306	3.291
α_{FT}	-		0.919	7.776	-	
α_{MT}	22.507*	2.178	-12.079	11.59	-4.732	3.913
$R^2_{capital}$	0.71		0.62		0.93	
R^2_{labour}	0.47		0.64		0.94	
$R^2_{materials}$	0.93		0.2		0.63	
R^2_{fuel}	-		0.79		-	

Notes:
1/ Asymptotic standard errors (SE). The sample sizes are, respectively, N=35, N=31, and N=27
* significant at the .01 level
‡ significant at the .05 level
† significant at the .1 level

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