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The Impact of Ownership Unbundling on Cost Efficiency: Empirical Evidence from the New Zealand Electricity Distribution Sector

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Preliminary version, please do not quote!

Several countries around the world have introduced reforms to the electric power sector. One important element of these reforms is the introduction of an unbundling process, i.e., the separation of the competitive activities of supply and production from the monopole activity of transmission and distribution of electricity. There are several forms of unbundling: functional, legal and ownership. New Zealand, for instance, adopted an ownership unbundling in 1998. As discussed in the literature, ownership unbundling produces benefits and costs. One of the benefits may be an improvement in the level of the productive efficiency of the companies due to the use of the inputs in just one activity and a greater level of transparency for the regulator. This paper analyzes the cost efficiency of 28 electricity distribution companies in New Zealand for the period between 1996 and 2011. Using a stochastic frontier panel data model, a total cost function and a variable cost function are estimated in order to evaluate the impact of ownership unbundling on the level of cost efficiency. The results indicate that ownership separation of electricity generation and retail operations from the distribution network has a positive effect on the cost efficiency of distribution companies in New Zealand. The estimated effect of ownership separation suggests a positive average one-off shift of 23 percent in the level of cost efficiency in the short-run and 15 percent in the long-run.

Keywords: Electricity distribution, Ownership separation, Cost efficiency, Total cost function, Variable cost function, Stochastic frontier analysis

JEL classification: L51, L94, D24

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1 Introduction

Historically, electricity sectors all around the world were characterized by vertically integrated, mainly state-owned monopolies. Beginning with the early 1980s, many countries started to liberalize their electricity markets with the aim to introduce more competition and to improve efficiency. A major element of all reforms was the unbundling of the competitive generation and retail segments from the non-competitive network segments (i.e., transmission and distribution). Up to now, many countries have implemented some kind of functional or legal unbundling, while the strictest form of unbundling, i.e., ownership separation, has only been adopted by New Zealand in 1998 and the Netherlands in 2011 (Shen and Yang, 2012).

As discussed in de Nooij and Baarsma (2009), the introduction of ownership unbundling, i.e. a situation in which transmission and distribution networks are operated under different ownership than generation/production and supply, can result in various costs and benefits. The main argument in favor of ownership separation is that, via a more transparent regulated third part access to network, it is possible to increase the level of competition on the wholesale and retail competitive markets. Furthermore, ownership separation would eliminate the possibility of cross subsidization, force the companies to concentrate their resources just in one activity, increase transparency for the regulation authority and thereby create incentives for the network owners to operate more cost-efficiently. On the other hand, we should consider that the separation of ownership may imply the loss of economies of vertical integration.[1]

There are few studies that analyze the costs and benefits of ownership unbundling in the electricity sector. Most of these studies analyze the introduction of ownership unbundling to transmission networks (e.g. Pollitt, 2008; Pielow et al., 2009), whereas only two studies analyze the effects of ownership unbundling on electricity distribution companies.

In the first study, de Nooij and Baarsma (2009) propose an ex ante cost-benefit analysis of the ownership unbundling of distribution companies in the Dutch electricity sector. The results of the analysis show that ownership unbundling would decrease welfare. In their analysis, de Nooij and Baarsma (2009) mention explicitly that ownership unbundling has a positive impact on the level of productive efficiency of the companies. However, due to a lack of data, they were not able to approximate the impact of ownership unbundling on the productive efficiency using an econometric approach.

The second study by Nillesen and Pollitt (2011) analyzes the impact of the introduction of ownership unbundling on electricity prices, quality of service and costs using a sample of electricity distribution companies operating in New Zealand. For this purpose, they propose a relatively simple empirical method based on the estimation of a Cobb-Douglas variable cost function, using data from 1995 to 2007 for 28 electricity distribution companies, and applying a fixed effects as well as a random effects model. The variable cost model specification used by Nillesen and Pollitt (2011) includes the

[1] For a discussion of empirical works on the economies of vertical integration, see Fetz and Filippini (2010).

explanatory variables: output, a variable on the customer density, a variable on the quality of the service, a time trend and a dummy variable related to the introduction of the ownership unbundling. The results of this study show that ownership unbundling has an impact on unit operational costs. This is an interesting study, however with some limitations. First, the variable cost model specification used by Nillesen and Pollitt (2011) does not include in the explanatory variables, contrary to what is suggested in microeconomic theory of production, a variable representing the capital. Second, a relatively rigid functional form of the Cobb-Douglas is used. Finally, this study analyzes the impact of ownership unbundling on the level of the cost and not on the level of cost efficiency. Of course, we are aware that these two types of analyses are related. However, due to the fact that regulation authorities use benchmarking analyses of the cost, an analysis on the impact of this type of unbundling on the level of cost efficiency is more interesting from a regulation point of view.

The aim of this paper is, therefore, to analyze the impact of ownership separation on the level of cost efficiency of the electricity distribution companies in New Zealand. For this purpose, we estimate several stochastic cost frontier functions utilizing a panel data set of 28 electricity distribution companies for the period between 1996 and 2011. To obtain robust results, we estimate both a total cost function and a variable cost function. The total cost function expresses the long-term cost performance assuming that firms are in static equilibrium and use all their inputs at an optimal level. However, this is a strong assumption because electricity distribution utilities can not easily adjust their stock of capital. The variable cost function takes this into account. It reflects the short-term cost performance accounting for the quasi-fixed character of the distribution network.

Our approach differs from the approach used by Nillesen and Pollitt (2011) in several aspects. First, we use a more flexible functional form. Second, we investigate the impact of ownership separation on cost efficiency. Finally, our results are based on a greater amount of actual data with observations available up to the year 2011. Therefore, our study may be interpreted as an in-depth analysis of the study by Nillesen and Pollitt (2011). The results of our study are relevant for practitioners and theorists. Politicians and regulators in many countries still debate about the economic advantages and disadvantages of ownership separation, not only in the electricity markets but also in other network industries such as rail transport or natural gas distribution. Within this discussion, the question as to whether ownership separation increases or decreases cost efficiency is one important issue.

The remainder of the paper is organized as follows: Section 2 briefly discusses ownership separation in New Zealand's electricity sector. The estimation methodology is introduced in Section 3, while Sector 4 describes the data. The estimation results are presented in Section 5. Section 6 summarizes and concludes.

2 Ownership unbundling in the New Zealand electricity sector

Prior to the electricity market reforms in the mid-1980s, almost 100 percent of the electricity generation capacity and the transmission grid in New Zealand's electricity sector were controlled by the government, namely the New Zealand Electricity Department (NZED). Retail and distribution were provided by 61 publicly-owned local franchise monopolies, the so-called Electrical Supply Authorities (ESAs). In April 1987, the government converted NZED into a state-owned enterprise, the Electricity Corporation of New Zealand (ECNZ). A couple of years later in 1992, the ESAs were corporatized and in 1994, the publicly-owned transmission grid company Transpower was formed. In 1996, parts of ECNZ's generation assets were transferred to the newly founded and publicly-owned generation company Contact Energy (Bertram, 2006)

However, all these reforms did not meet the objective of the liberalization process: To improve efficiency and consumer welfare by increasing competition in generation and retail and by eliminating cross subsidization of the potentially competitive generation and retail segment from the non-competitive distribution segment (Shen and Yang, 2012).

Given this unsatisfactory development, New Zealand's government enacted the Electricity Industry Reform Act (EIRA) in 1998. The two main elements of the EIRA were the splitting of ECNZ into three competing publicly-owned companies and the ownership separation of distribution from retailers. Between July 1998 and April 1999, the vast majority of distribution companies sold their retail operations. In the following years, several acquisitions and mergers gradually reduced the number of electricity distribution businesses in New Zealand to 28 in 2008. In 2009, the number increased back to 29 utilities as Vector sold its Wellington network (Shen and Yang, 2012).

As of now, the final act of ownership separation in New Zealand's electricity sector took place in 2010, when New Zealand's government introduced the Electricity Industry Act (EIA). The EIA partly relaxes the strict ownership separation of distribution and generation from retail by allowing a re-bundling up to a maximum threshold (Shen and Yang, 2012).

3 Cost model specifications and estimation methods

Previous studies on the cost structure of electricity distribution companies are numerous.[2] Generally, these studies consider the estimation of a total or variable cost function using a flexible functional form. Moreover, the most used explanatory variables in these studies include: the electricity supplied measured in kilowatt-hours, the number of customers and the factor prices, as well as some output characteristic variables such as the customer density, the network size, the service area and the load factor.

In our analysis, we estimate both a variable and a total cost function. For this purpose, we specify a total cost function with two outputs and three output characteristic variables. Unfortunately, due to a lack of data, we are not able to introduce the input

[2] For a discussion on the estimation of cost functions in the energy sector and a review of previous studies, see Ramos-Real (2005) and Farsi and Filippini (2009).

prices in the cost model specification. Therefore, following Nillesen and Pollitt (2011), we assume that all firms in New Zealand's electricity distribution sector are subject to the same input prices.

If it is assumed that the firm minimizes cost and that the isoquants are convex, a total cost function can be written as

$$TC = C(QE, QC, LF, SAIDI, CD, DT), \tag{1}$$

where TC represents total cost; QE is the electricity supplied in kilowatt-hours; QC is the number of final consumers; LF denotes load factor; $SAIDI$ is an index on the average interruption duration of the system; CD is consumer density; and DT represents time dummies which capture changes over time. A detailed description of these variables and their expected impact on costs is carried out in the subsequent data section (see Section 3). Economic theory requires the total cost function given in Equation (1) to be concave and linearly homogeneous in input prices and non-decreasing in input prices and outputs.[3]

Estimation of cost function (1) requires the specification of a functional form. The translog function offers an appropriate functional form, because it imposes no a priori restrictions on the nature of technology. The translog approximation of (1) in the form of a total cost frontier function is

$$\begin{aligned}
ln\, TC_{it} &= \alpha_0 + \alpha_{QE}\, ln\, QE_{it} + \alpha_{QC}\, ln\, QC_{it} + \alpha_{LF}\, ln\, LF_{it} + \alpha_{SAIDI}\, ln\, SAIDI_{it} \\
&+ \alpha_{CD}\, ln\, CD_{it} + \frac{1}{2}\alpha_{QE,QE}\, ln\, QE_{it}\, ln\, QE_{it} + \frac{1}{2}\alpha_{QC,QC}\, ln\, QC_{it}\, ln\, QC_{it} \\
&+ \frac{1}{2}\alpha_{LF,LF}\, ln\, LF_{it}\, ln\, LF_{it} + \frac{1}{2}\alpha_{SAIDI,SAIDI}\, ln\, SAIDI_{it}\, ln\, SAIDI_{it} \\
&+ \frac{1}{2}\alpha_{CD,CD}\, ln\, CD_{it}\, ln\, CD_{it} + \alpha_{QE,QC}\, ln\, QE_{it}\, ln\, QC_{it} + \alpha_{QE,LF}\, ln\, QE_{it}\, ln\, LF_{it} \\
&+ \alpha_{QE,SAIDI}\, ln\, QE_{it}\, ln\, SAIDI_{it} + \alpha_{QE,CD}\, ln\, QE_{it}\, ln\, CD_{it} \\
&+ \alpha_{QC,LF}\, ln\, QC_{it}\, ln\, LF_{it} + \alpha_{QC,SAIDI}\, ln\, QC_{it}\, ln\, SAIDI_{it} \\
&+ \alpha_{QC,CD}\, ln\, QC_{it}\, ln\, CD_{it} + \alpha_{LF,SAIDI}\, ln\, LF_{it}\, ln\, SAIDI_{it} \\
&+ \alpha_{LF,CD}\, ln\, LF_{it}\, ln\, CD_{it} + \alpha_{SAIDI,CD}\, ln\, SAIDI_{it}\, ln\, CD_{it} \\
&+ \sum_{t=2}^{T} \alpha_t\, DT_t + v_{it} + u_{it},
\end{aligned} \tag{2}$$

where the subscripts i and t denote the firm and year, respectively; and the αs are unknown parameters to be estimated. The error term in (2) is assumed, as usually done in the specification of a stochastic frontier model, to be composed of two independent

[3] For more details on the properties of cost functions, see, e.g., Chambers (1988).

parts: A stochastic error (v_{it}), capturing the effect of noise, and a one-sided non-negative disturbance, capturing the effect of inefficiency ($u_{it} \geq 0$).

The previously defined total cost function model (1) invokes the assumption that electricity distribution companies are in static equilibrium, using all inputs at their optimal levels. This assumption may be fallacious. For this reason, we also present a specification that allows for the possibility that firms are not in static equilibrium with respect to capital stock. If it is the case that the firms are not in equilibrium with respect to this quasi-fixed input, then measures of economies of scale and cost efficiency obtained from the estimates of the long-run cost function may be not precise.

The variable cost function is written in the same manner as the total cost function (1), except that the variable cost (VC) replaces total cost as the dependent variable and a proxy for the capital stock (K) is added. The corresponding translog variable cost frontier function to our translog total cost frontier function defined in Equation (2), can be written as

$$\begin{aligned}
&ln\,VC_{it} = \alpha_0 + \alpha_{QE}\,ln\,QE_{it} + \alpha_{QC}\,ln\,QC_{it} + \alpha_{K}\,ln\,K_{it} + \alpha_{LF}\,ln\,LF_{it} \\
&+ \alpha_{SAIDI}\,ln\,SAIDI_{it} + \alpha_{CD}\,ln\,CD_{it} + \frac{1}{2}\,\alpha_{QE,QE}\,ln\,QE_{it}\,ln\,QE_{it} \\
&+ \frac{1}{2}\,\alpha_{QC,QC}\,ln\,QC_{it}\,ln\,QC_{it} + \frac{1}{2}\,\alpha_{K,K}\,ln\,K_{it}\,ln\,K_{it} \\
&+ \frac{1}{2}\,\alpha_{LF,LF}\,ln\,LF_{it}\,ln\,LF_{it} + \frac{1}{2}\,\alpha_{SAIDI,SAIDI}\,ln\,SAIDI_{it}\,ln\,SAIDI_{it} \\
&+ \frac{1}{2}\,\alpha_{CD,CD}\,ln\,CD_{it}\,ln\,CD_{it} + \alpha_{QE,QC}\,ln\,QE_{it}\,ln\,QC_{it} \\
&+ \alpha_{QE,K}\,ln\,QE_{it}\,ln\,K_{it} + \alpha_{QE,LF}\,ln\,QE_{it}\,ln\,LF_{it} \\
&+ \alpha_{QE,SAIDI}\,ln\,QE_{it}\,ln\,SAIDI_{it} + \alpha_{QE,CD}\,ln\,QE_{it}\,ln\,CD_{it} \\
&+ \alpha_{QC,K}\,ln\,QC_{it}\,ln\,K_{it} + \alpha_{QC,LF}\,ln\,QC_{it}\,ln\,LF_{it} + \alpha_{QC,SAIDI}\,ln\,QC_{it}\,ln\,SAIDI_{it} \\
&+ \alpha_{QC,CD}\,ln\,QC_{it}\,ln\,CD_{it} + \alpha_{K,LF}\,ln\,K_{it}\,ln\,LF_{it} + \alpha_{K,SAIDI}\,ln\,K_{it}\,ln\,SAIDI_{it} \\
&+ \alpha_{K,CD}\,ln\,K_{it}\,ln\,CD_{it} + \alpha_{LF,SAIDI}\,ln\,LF_{it}\,ln\,SAIDI_{it} \\
&+ \alpha_{LF,CD}\,ln\,LF_{it}\,ln\,CD_{it} + \alpha_{SAIDI,CD}\,ln\,SAIDI_{it}\,ln\,CD_{it} \\
&+ \sum_{t=2}^{T}\,\alpha_t\,DT_t + v_{it} + u_{it}.
\end{aligned} \tag{3}$$

The variable cost function assumes that firms minimize variable cost given input prices, capital stock and output. As for the total cost frontier function, we assume that the input prices are the same for all firms and therefore do not include them in our variable cost frontier function specification. A well-defined variable cost frontier function should be increasing with respect to output and input prices, concave with respect to input prices and non-increasing with respect to capital stock.[4]

In the literature on the estimation of stochastic frontier models using panel data, it is possible to identify several models that could be used for the estimation of Equations (2) and (3). In this study, the focus is on the effects of ownership unbundling on the level of cost efficiency. Therefore, we select the stochastic frontier models for panel data that allow for the level of cost efficiency to vary over time and to depend on a set of covariates such as the presence of ownership unbundling. For this purpose, three suitable panel data models are identified: i) the panel data model proposed by Battese and Coelli (1995) (BC95 hereafter); ii) the True Random Effects model (TRE hereafter); and iii) the True Fixed Effects model (TFE hereafter).[5] The two latter models have been proposed more recently by Greene (2005*a*,*b*). All these approaches allow for the estimation of a stochastic frontier model in which the level of efficiency can be expressed as a specific function of explanatory variables.

In this study, we use the BC95 model and a version of this model that specifically takes into account the unobserved heterogeneity problem. In fact, the BC95 model can suffer from the 'unobserved variables bias' because the unobserved characteristics may not be distributed independently of the explanatory variables. In order to address the unobserved heterogeneity bias, a fixed-effects version of the BC95 model is estimated as well. The main difference between the TFE model and the BC95 with fixed effects (BC95 FE) is that the former is estimated without introducing the firm-specific dummy variables directly into the equation and uses a simulated maximum likelihood approach, whereas the latter is estimated using a maximum likelihood approach and introducing the firm-specific dummy variables directly into the model.[6]

Assuming that ownership separation directly affects cost efficiency and following Battese and Coelli (1995), the inefficiency term u_{it} in Equations (2) and (3) is modified so as to have a systematic component associated with the variable related to the introduction of the ownership unbundling ($Sepa_{it}$) and a random component (e_{it}):[7]

$$u_{it} = \eta' z_{it} + e_{it}, \tag{4}$$

where $z_{it} = Sepa_{it}$ is a dummy variable equal to 1 if firm i is characterized by ownership unbundling in period t, and 0 otherwise; and η' represents unknown parameters to be estimated.

This model can be estimated in a single stage by the maximum likelihood procedure in which the stochastic term is assumed to follow a normal distribution $v_{it} \sim iidN(0, \sigma_v^2)$

[4] See, e.g., Chambers (1988).

[5] For a general discussion on the use of stochastic frontier models in the energy sector, see Farsi and Filippini (2009).

[6] Because of the different estimation procedure, the two models will not produce the same results. From the estimation point of view, the dummy variable panel model is better because it does not need to use a simulated maximum likelihood estimator that may not always converge.

[7] Battese and Coelli (1995) extend the approach by Kumbhakar et al. (1991) to accommodate panel data. However, it should be noted that this model does not in fact exploit the panel aspect of the data set in order to deal with the unobserved heterogeneity.

and the inefficiency term is assumed to follow a truncated normal distribution $u_{it} \sim N^{+}(\eta' z_{it}, \sigma_u^2)$. Since only the composed error term $\epsilon_{it} = v_{it} - u_{it}$ is observed, the firm's inefficiency is predicted by the conditional mean $\hat{u}_{it} = E[u_{it}|\epsilon_{it}]$, where $\epsilon_{it} = v_{it} + u_{it}$ (Jondrow et al., 1982). Cost efficiency for firm i in period t can then be calculated as $CE_{it} = exp(-\hat{u}_{it})$.

4 Data

The total and variable cost function analysis is based on panel data from 28 of New Zealand's electricity distribution businesses (EDBs) for the period 1996-2011. With only three missing observations, the panel covers almost 100 percent of New Zealand's entire electricity distribution sector during the observed time period.[8] The main data source is the "NZ EDB Database" from Economic Insights, which collects financial and production data for the EDBs from the Electricity Information Disclosures, required by New Zealand's electricity regulations to be published annually (Economic Insights, 2009). The Economic Insights' database covers the period 1996-2008. We augmented the database by three more years, once again using data from the Electricity Information Disclosures.

To define our variable and total cost functions, we consider two outputs: the number of consumers and the electricity supplied in kilowatt-hours. Together these outputs reflect the two elements of the joint service of electricity distribution: network connection and electricity supply (Neuberg, 1977). The company size in our sample ranges from around 4,100 to nearly 680,000 connected consumers. The largest company is Vector, which operates the electricity distribution network in the greater Auckland region. The smallest company is Buller, located on the west coast of the South Island of New Zealand.

The two cost measures, variable and total cost, are adjusted for inflation using the consumer price index for New Zealand provided by the OECD. Values are stated in year-2005 New Zealand dollars. Variable cost reflects the operating expenses for labor, materials and services. Total cost is defined as the sum of variable cost and capital cost. Unfortunately, the Electricity Information Disclosures do not provide consistent information on capital cost for the whole observed period. However, they do provide information on the annual monetary value of the system fixed assets, the so-called optimized deprival value (ODV). Basically, the ODV represents the loss of value that an EDB would sustain if deprived of the assets.[9] Following Lawrence (2003) and Lawrence et al. (2009), we assume a common depreciation rate of 4.5 percent of ODV and an opportunity cost rate of 8 percent of ODV to measure the cost of capital. Therefore, capital cost is approximated to be 12.5 percent of the annual ODV.

The capital stock for the variable cost function model is defined as the maximum distribution transformer demand in megawatts. This definition represents a capacity

[8] In 2009, Vector sold its network in Wellington, which became a separate business (Shen and Yang, 2012). Because of the short time series, we do not include Wellington Electricity in our analysis.

[9] For a detailed overview of the ODV methodology used for asset valuations in New Zealand's electricity distribution sector, see New Zealand Commerce Commission (2004).

measure of the capital stock and reflects the maximum output that a given network can handle at any one point in time.[10] We opt for this measure of the capital stock rather than for the ODV because the former seems to be more appropriate to reflect the quasi-fixed input characteristic of the capital stock in an industry with peak-load requirements.[11]

In addition to the inputs and outputs, we also include three network characteristics in our analysis. The first is the load factor that represents the intensity of utilization of the distribution network. It is defined as the electricity supplied divided by the maximum distribution transformer demand multiplied by the total number of hours in one year. We expect a negative sign for the load factor coefficient, indicating lower costs for distribution firms with higher rates of network utilization.

Second, we consider a quality factor. SAIDI. This factor measures the average number of interruption minutes for a consumer within a given period. Lower quality, that is a higher SAIDI, can lead to higher costs. Hence, a negative sign for the coefficient is expected.

Third, we include consumer density, defined as the number of consumers per kilometer of network length. Again, we expect a negative coefficient, indicating that networks with a higher consumer density can operate at lower costs than other networks. Table 1 presents some descriptive statistics of the variables considered in our analysis.

Table 1: Descriptive statistics

Variable	Unit of Measurement	Mean	Std. Dev.	Minimum	Maximum
Variable cost	Million 2005$	10,700	16,300	837	119,000
Total cost	Million 2005$	35,500	56,900	3,359	378,000
Electricity supplied	MWh	865,000	1,540,000	36,882	10,695,855
Consumers	Number	56,614	99,923	4,108	679,612
Capital stock	MW	166	303	8	2,216
Load Factor	Percentage	62	7	30	85
SAIDI	Minutes	237	199	15	1,918
Consumer density	Consumers per line km	11	7	3	38

[10] See Filippini (1996) for a similar approach.

[11] In a preliminary analysis, we also used ODV as the measure for capital stock. However, we obtained a positive coefficient for the capital stock, which is not consistent with microeconomic theory. This finding is not unusual for studies on the cost structure of electricity distribution firms. As noted by Filippini (1996), the positive sign of the capital stock coefficient can result from multicollinearity problems between the outputs and the capital stock.

5 Results

The estimated parameters for the variable and total cost frontier functions defined in Equations (2) and (3) and estimated with the BC95 and BC95 FE models are presented in Table 2.

The first model, the BC95, has been adopted in a number of studies that analyze efficiency based on panel data. However, since the model treats all observations as independent, it is not a 'real' panel data model. Rather, it is a pooled model that does not use the panel structure of the data to control for the unobserved heterogeneity. Nevertheless, we include this model in our analysis for comparison reasons.

The second model, the BC95 FE, adds a set of firm dummy variables to the cost function specifications. These variables capture unobserved firm-specific heterogeneity, e.g. differences in the environmental characteristics of the service area that may influence the firm-specific cost structure.

Since total cost, variable cost and the regressors are in logarithmic form and the regressors have been normalized, the first-order coefficients can be interpreted as the cost elasticities evaluated at the sample median.

Overall, the results show that all first-order coefficients are statistically significant at the 5 percent level and have the expected signs across all models. That is to say, at the approximation point, the variable and the total cost frontier functions are increasing in outputs and the variable cost frontier function is, as expected from a theoretical point of view, decreasing in capital stock. The magnitude of the coefficients differs among the BC95 and the BC95 FE models. This difference is probably due to the unobserved heterogeneity bias. In fact, the result of a likelihood-ratio test indicates that as a group, the parameters of the firm-specific effects are significantly different from zero. For this reason, the following discussion is mostly based on the results obtained from the BC95 FE models.

Comparing the results of the variable and total cost functions, the estimated coefficients provide some interesting insights into the short- and long-run cost structures of the firms. The output coefficients are rather similar in the two fixed effects models. For example, the corresponding coefficients for the number of customers imply that a 1 percent increase in the number of customers will increase the variable cost by approximately 0.8 percent and the total cost by approximately 0.7 percent at the sample median. The coefficients for the second output show even more similarity, suggesting a 1 percent increase in electricity supplied will result in an average approximate increase of 0.4 percent in both variable and total cost.

In contrast, differences in the short- and long-run cost structures can be observed when related to the network characteristics. The coefficient for SAIDI is statistically significant at the 10 percent level in the variable cost function only. The rather small magnitude of the coefficient (0.035) indicates a slight increase in the variable cost as a result of an increase in the average number of interruption minutes per customer. On the other hand, a highly statistically significant coefficient for consumer density is seen in the total cost function. A 1 percent increase in consumer density will decrease total cost by approximately 0.3 percent at the sample median. This result suggests

Table 2: Parameter estimates[a,b,c]

		Variable cost function				Total cost function			
		BC95		BC95 FE		BC95		BC95 FE	
Variable	Parameter	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. error	Coef.	Std. Err.
Constant	α_0	15.217	(0.079)	15.054	(0.144)	16.501	(0.038)	16.272	(0.059)
$ln\,QE$	α_{QE}	0.433	(0.180)	0.374	(0.172)	0.169	(0.034)	0.358	(0.061)
$ln\,QC$	α_{QC}	0.825	(0.064)	0.805	(0.176)	0.797	(0.039)	0.662	(0.088)
$ln\,K$	α_K	−0.376	(0.185)	−0.313	(0.130)				
$ln\,LF$	α_{LF}	−0.220	(0.224)	−0.238	(0.167)	−0.059	(0.094)	−0.020	(0.064)
$ln\,SAIDI$	α_{SAIDI}	0.056	(0.020)	0.035	(0.019)	0.013	(0.011)	−0.010	(0.008)
$ln\,CD$	α_{CD}	−0.120	(0.037)	−0.079	(0.126)	−0.364	(0.021)	−0.273	(0.058)
$(ln\,QE)^2$	$\alpha_{QE,QE}$	−0.139	(0.600)	−0.395	(0.516)	0.403	(0.126)	−0.075	(0.151)
$(ln\,QC)^2$	$\alpha_{QC,QC}$	−0.551	(0.283)	0.265	(0.403)	0.335	(0.166)	−0.240	(0.235)
$(ln\,K)^2$	$\alpha_{K,K}$	−0.205	(0.846)	−0.197	(0.686)				
$(ln\,LF)^2$	$\alpha_{LF,LF}$	0.500	(0.968)	0.601	(0.715)	0.028	(0.362)	−0.092	(0.223)
$(ln\,SAIDI)^2$	$\alpha_{SAIDI,SAIDI}$	−0.079	(0.031)	−0.020	(0.025)	−0.027	(0.020)	0.003	(0.011)
$(ln\,CD)^2$	$\alpha_{CD,CD}$	−0.039	(0.092)	0.101	(0.331)	0.156	(0.058)	0.056	(0.163)
$ln\,QE \times ln\,QC$	$\alpha_{QE,QC}$	0.546	(0.428)	0.183	(0.355)	−0.348	(0.136)	0.113	(0.179)
$ln\,QE \times ln\,K$	$\alpha_{QE,K}$	0.320	(0.606)	0.430	(0.524)				
$ln\,QE \times ln\,LF$	$\alpha_{QE,LF}$	−1.482	(0.753)	−1.199	(0.739)	−1.274	(0.182)	−0.333	(0.148)
$ln\,QE \times ln\,SAIDI$	$\alpha_{QE,SAIDI}$	0.045	(0.166)	0.287	(0.112)	0.017	(0.037)	0.063	(0.022)
$ln\,QE \times ln\,CD$	$\alpha_{QE,CD}$	−1.495	(0.438)	−0.474	(0.358)	−0.146	(0.081)	−0.211	(0.118)
$ln\,QC \times ln\,K$	$\alpha_{QC,K}$	−0.412	(0.365)	−0.434	(0.261)				
$ln\,QC \times ln\,LF$	$\alpha_{QC,LF}$	1.031	(0.453)	0.574	(0.469)	1.292	(0.190)	0.329	(0.155)
$ln\,QC \times ln\,SAIDI$	$\alpha_{QC,SAIDI}$	−0.159	(0.064)	−0.164	(0.049)	−0.056	(0.040)	−0.074	(0.022)
$ln\,QC \times ln\,CD$	$\alpha_{QC,CD}$	0.249	(0.131)	−0.374	(0.287)	0.150	(0.079)	0.287	(0.141)
$ln\,K \times ln\,LF$	$\alpha_{K,LF}$	0.524	(0.792)	0.876	(0.685)				
$ln\,K \times ln\,SAIDI$	$\alpha_{K,SAIDI}$	0.081	(0.169)	−0.162	(0.105)				
$ln\,K \times ln\,CD$	$\alpha_{K,CD}$	1.283	(0.441)	0.654	(0.344)				
$ln\,LF \times ln\,SAIDI$	$\alpha_{LF,SAIDI}$	0.238	(0.186)	−0.186	(0.135)	0.244	(0.077)	0.053	(0.041)
$ln\,LF \times ln\,CD$	$\alpha_{LF,CD}$	1.137	(0.498)	0.463	(0.396)	−0.029	(0.171)	0.137	(0.121)
$ln\,SAIDI \times ln\,CD$	$\alpha_{SAIDI,CD}$	−0.087	(0.042)	0.002	(0.032)	−0.026	(0.024)	0.009	(0.014)
Time dummies	α_t	yes		yes		yes		yes	
Firm dummies	α_f	no		yes		no		yes	
Inefficiency									
Constant	η_0	0.322	(0.212)	0.563	(0.129)	−0.471	(0.786)	0.202	(0.116)
Sepa	η_1	−0.712	(0.207)	−0.869	(0.172)	−0.681	(0.527)	−1.022	(0.354)
Log likelihood	llf	84.941		247.055		296.211		582.620	
Sigma u	σ_u	0.406	(0.081)	0.258	(0.032)	0.419	(0.181)	0.207	(0.047)
Sigma v	σ_v	0.078	(0.015)	0.067	(0.013)	0.055	(0.007)	0.034	(0.004)
Lambda	$\lambda = \sigma_u/\sigma_v$	5.186	(0.080)	3.877	(0.034)	7.600	(0.178)	6.090	(0.047)

[a]Standard errors in parentheses.[b]The estimated coefficients of the time and firm dummy variables are not reported to conserve space. A complete list of these coefficients is available from the authors upon request. [c]All estimations have been performed in Stata 12.1 using the sfpanel command developed by Belotti et al. (2012).

that electricity distribution firms operating a highly dense network may benefit from economies of density

As we are most interested in the impact of ownership separation on the cost efficiency in New Zealand's electricity distribution sector, we now turn our attention to the separation variable in our models. As shown in Table 2, the sign of the separation coefficient is negative in all models. Furthermore, in both fixed effects models and in the pooled model for the variable cost function, the coefficient is statistically significant on the 1 percent level. From these results, we can conclude that ownership separation had a negative effect on cost inefficiency and, thus, a positive effect on cost efficiency. However, the estimated coefficients only indicate the direction of the effect. Following Zhu et al. (2008), a quantification of the marginal effect of ownership separation on cost efficiency can be obtained from

$$\frac{\partial \, CE_{it}}{\partial \, Sepa_{it}} = -CE_{it} \times \frac{\partial \, E(u_{it})}{\partial \, Sepa_{it}}, \tag{5}$$

where $CE_{it} = exp(-\hat{u}_{it})$ is the predicted cost efficiency score and $\frac{\partial \, E(u_{it})}{\partial \, Sepa_{it}}$ is the partial derivation of the inefficiency predictor with respect to the separation variable.

Table 3 presents the estimated marginal effect of ownership separation on efficiency. Since ownership separation is modeled as a dummy variable, the estimated values represent a one-off shift in efficiency rather than a marginal effect. Focusing on the more reliable fixed effects results, we observe a positive one-off shift of approximately 23 percent in the short-run cost efficiency and approximately 15 percent in the long-run cost efficiency.

Table 3: Marginal effects

	Variable cots function		Total cost function	
	BC95	BC95 FE	BC95	BC95 FE
Average marginal effect of ownership separation on cost efficiency	0.152	0.227	0.059	0.145

The estimation results reported in Table 2 can be also used to compute the value of the economies of scale. Economies of scale (ES) are defined as the proportional increase in total costs brought about by a proportional increase in outputs, holding all other explanatory variables fixed. Economies of scale (ES) can thus be defined for the total cost frontier function as

$$ES_{TC} = \frac{1}{\dfrac{\partial \, ln \, TC}{\partial \, ln \, QE} + \dfrac{\partial \, ln \, TC}{\partial \, lnQC}}. \tag{6}$$

We identify economies of scale if ES is greater than 1, and accordingly, we identify diseconomies of scale if ES is below 1. Following Caves et al. (1981), economies of scale (ES) for the variable cost frontier function can be defined as

$$ES_{VC} = \frac{1 - \dfrac{\partial \, ln \, VC}{\partial \, ln \, K}}{\dfrac{\partial \, ln \, VC}{\partial \, ln \, QE} + \dfrac{\partial \, ln \, VC}{\partial \, lnQC}}. \tag{7}$$

Table 4 presents the estimates of economies of scale computed for a medium sized firm.[12] We note that the indicators for economies of scale computed, using the results obtained from the variable cost frontier function, are greater than 1, whereas the values of the economies of scale obtained from the total cost frontier function are approximately equal to 1. However, since the total cost frontier function considers all inputs as freely adjustable, this result may be imprecise. For this reason, we tend to support the hypothesis that the electricity distribution sector is characterized by economies of scale.

Table 4: Economics of scale

Variable cost function		Total cost function	
1.094	1.114	1.035	0.980

Finally, Table 5 provides descriptive statistics for the level of cost efficiency of the 28 companies. The values reported in the table show that the estimated mean average efficiency is about 80 percent in the variable cost frontier model and about 90 percent in the total cost frontier model.

Table 5: Summary statistics of cost efficiency scores

	Variable cost function		Total cost function	
	BC95	BC95 FE	BC95	BC95 FE
Mean	0.785	0.829	0.875	0.922
Std. Dev.	0.151	0.150	0.100	0.091
Minimum	0.304	0.280	0.517	0.446
Maximum	0.971	0.982	0.982	0.992

6 Conclusions

The purpose of this study was to estimate cost frontier models for the electricity distribution companies operating in New Zealand in order to assess the impact of ownership unbundling on the level of cost efficiency. For this purpose, a translog total cost frontier

[12] Equations (6) and (7) have been evaluated at the values for the load factor, SAIDI and consumer density of the median company. For the interpretation of the results, it is important to note that a proportional increase in electricity supplied and number of consumers implies, keeping the value of the consumer density constant, an increase in the network length.

function and a translog variable cost frontier function were estimated using panel data for a sample of 28 of New Zealand's electricity distribution companies over the period 1996-2011. In both models, the results indicate the existence of a positive impact of the introduction of ownership unbundling on the level of cost efficiency.

The empirical evidence confirms the results obtained by Nillesen and Pollitt (2011) and suggests, as discussed in de Nooij and Baarsma (2009), that ownership unbundling has a positive impact on the level of productive efficiency of the companies. Of course, from a welfare economics perspective, if the introduction of ownership unbundling in New Zealand has increased the welfare requires a complete cost-benefits analysis as suggested by de Nooij and Baarsma (2009). Our paper is therefore a piece of the puzzle that should be completed by other studies on the economies of vertical integration, economies of scope and allocative efficiency gains pertaining to the electricity market.

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