Technological Externalities and Economies of Vertical Integration in the Electric Utility Industry

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Abstract:

This paper investigates economies of vertical integration of the electric utility industry, focusing on the technological externality between the generation and transmission-distribution stages. For this purpose, a shadow cost function of the symmetric generalized McFadden form is estimated using panel data on the transmission-distribution stage of nine Japanese electric utility firms. The results show that there exist the technological externality effects of generation facilities on the cost of the transmission-distribution stage, suggesting economies of vertical integration.

Key Words: economies of vertical integration, shadow cost function, allocative inefficiency, electric utility industry

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1. Introduction

In the last two decades, the policy view on public utilities has dramatically changed, favoring competition under the market mechanisms over regulation by the government. Those changes in views on the electric industry are based on the belief that the generation stage has exhausted scale economies, while the transmission and distribution stages maintain their natural monopolistic characters. Indeed, in the U.K. the divestiture of a monopolistic supplier, the Central Electricity Generating Board, was executed by separating the generation stage from the vertically integrated production process and placing it in a competitive market environment. Several U.S. states have also pursued vertical disintegration of incumbent utilities so as to introduce competition in the generation stage.

However, the electric industry is characterized by strong technological links among different stages of the production process. Even if electric generation is no longer a natural monopoly, vertical disintegration may cause a loss of cost efficiency. This paper aims to investigate economies of vertical integration, focusing on the technological externality between the generation and transmission-distribution stages.

To the best of our knowledge, there are two approaches for testing economies of vertical integration. One is a subadditivity test of the multioutput cost function in which an output of each stage is specified as one output of a vertically integrated firm. Following this approach, Kaserman and Mayo (1991) and Gilsdorf (1994) find evidence for the existence of economies of vertical integration. The other approach is to test separability among the production stages. If the generation stage is separable from the transmission-distribution stage, no benefit is gained by vertical integration because integrated and disintegrated processes are technologically equivalent. Lee (1995) tested the linear separability of the translog cost function and rejected separability hypotheses among generation, transmission and distribution stages. Hayashi, Goo and Chamberlain (1997) also provided supporting results for economies of vertical integration using a variant of the separability test.

Both approaches examine the cost function as a whole to judge whether a set of its parameters reflects any possibilities of cost savings due to vertical integration. They are, however, not explicit about the sources from which economies of integration arise. Although previous studies have generally agreed on the existence of some economies of vertical integration, it is still an open question to identify which aspects of the production process really cause such economies.

From an engineering viewpoint, the transmission-distribution facilities operate as a unified network together with the generating plants connected to them. A significant technological interdependency is thus most likely to be observed in the transmission-distribution stage in relation to the generation stage. This paper focuses on this point and examines whether the cost structure of transmission-distribution exhibits the effects of technological externality originating from the generation plants. If the generation plants cause such an externality in the transmission-distribution stage, centralized decision-making over the stages can produce economies of integration.

We estimate a cost function for transmission-distribution stage using panel data for nine Japanese electric utilities over the 1981-1998 period. Technological externality is examined by testing whether the generation plants act as a public input in the cost function. While our approach might be simple, it provides intuitively interpretable results and has direct implications for policy issues including vertical divestiture.

Unlike previous studies, we do not assume spontaneous adjustment of inputs to their optimal levels. The empirical literature on the electric industry has repeatedly claimed that departures from efficient firm behavior have been due to regulatory bias and fixity of the inputs. We employ a shadow cost function from which estimable demand equations for inputs are derived without constraining marginal rates of substitution to equal ratios of the corresponding input prices[1]. Taking advantage of panel data, we measure firm-specific allocative inefficiency varying over time.

The outline of the rest of this paper is as follows. Section 2 specifies the technological externality to be tested in this research. Section 3 specifies a cost function of the symmetric generalized McFadden form after briefly reviewing the methodology of the shadow cost function approach. Section 4 reports the empirical results. Section 5 gives concluding remarks.

2. Theoretical Framework

In this paper, we combine transmission and distribution into a single stage of production. The electric utility industry then involves two production stages: the upstream (generation) and the downstream (transmission and distribution) stage.

The upstream stage produces electricity from labor, X_L^U, fuel X_F^U, and capital X_K^U. The capital stock is assumed to be a quasi-fixed input that cannot be instantly adjusted, while labor and fuel are assumed as variable. The variable cost function of the upstream stage is then described as:

$$VC^U = VC^U\left(W_F^U, W_L^U, X_K^U, Y^U\right), \tag{1}$$

where W_L^U and W_F^U are wage rate and fuel price, respectively; Y^U is the electricity generated and VC^U variable costs of the generation stage. Superscript "U" indicates

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[1] The cost function model of this type was developed by Atkinson and Halvorsen (1984).

upstream.

The downstream stage retails electricity to final consumers using three inputs: labor X_L^D, capital X_K^D and electricity as an input X_E^D received from the upstream stage or purchased from other generation firms. Superscript " D " indicates downstream. The production function is described as

$$Y^D = f\left(X_L^D, X_E^D, X_K^D; X_K^U\right), \tag{2}$$

where Y^D is electricity delivered to final consumers. The capital stock of the upstream stage, X_K^U, appears in (2) to allow for technological externalities.

As with the upstream stage, capital is assumed to be a quasi-fixed input. The variable cost function conditioned on X_E^D of the downstream stage is then described as follows:[2]

$$\begin{aligned} VC^D &= VC^D\left(W_L^D, X_E^D, X_K^D, Y^D; X_K^U\right) \\ &= \min_{X_L^D}\left\{W_L^D X_L^D \;\middle|\; f\left(X_L^D, X_E^D, X_K^D; X_K^U\right) \geq Y^D\right\}. \end{aligned} \tag{3}$$

Here, W_L^D is wage rate, and VC^D is variable costs of the downstream stage. It is important to note that eq. (3) defines the variable costs of the downstream stage net of generation costs. Any technological externality is captured by the dependency of the downstream variable costs on X_K^U [3]. If the X_K^U does not affect transmission-distribution costs, there are no opportunities to reduce costs by jointly choosing all inputs of both stages. Conversely, economies of vertical integration exist if the generation capital stocks significantly raise or save the transmission-distribution costs.

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[2] If it is necessary to represent the generation costs explicitly, $VC^D + W_E^D X_E^D$ gives the gross variable costs of the downstream stage, where W_E^D denotes the price of electricity input.

[3] The externality considered here is purely technological. It does not matter if the generation plants are owned by the downstream stage.

For convenience, we define the total cost function conditioned on X_E^D of the transmission-distribution stage as:

$$\begin{aligned} &C^D\left(W_L^D, X_E^D, W_K^D, Y^D; X_K^U\right) \\ &\quad = \min_{X_K^D}\left\{VC^D\left(W_L^D, X_E^D, X_K^D, Y^D; X_K^U\right) + W_K^D X_K^D\right\}, \end{aligned} \tag{4}$$

where W_K^D is the user cost of the transmission-distribution capital[4]. Summing the total costs of the generation and the transmission-distribution stages gives the overall cost function:

$$\begin{aligned} &C\left(W, X_E^D, X_K^U, Y^U, Y^D\right) \\ &\quad = VC^U\left(W_L^U, W_F^U, X_K^U, Y^U\right) + W_K^U X_K^U + C^D\left(W_L^D, X_E^D, W_K^D, Y^D; X_K^U\right), \end{aligned} \tag{5}$$

where W_K^U is the user cost of generation capital and $W = (W_L^U, W_F^U, W_K^U, W_L^D, W_K^D)$. A vertically integrated electric utility firm can choose the optimal amounts of generation capital and electricity generated so as to minimize the overall costs (5). Suppose that a vertically integrated firm does not purchase electricity from other generation firms[5], i.e., $X_E^D = Y^U$. The first order condition for a vertically integrated firm is then:

$$\frac{\partial VC^U\left(W_L^U, W_F^U, X_K^U, Y^U\right)}{\partial Y^U} + \frac{\partial C^D\left(W_L^D, Y^U, W_K^D, Y^D; X_K^U\right)}{\partial Y^U} = 0, \tag{6}$$

and

$$\left\{\frac{\partial VC^U\left(W_L^U, W_F^U, X_K^U, Y^U\right)}{\partial X_K^U} + W_K^U\right\} + \frac{\partial C^D\left(W_L^D, Y^U, W_K^D, Y^D; X_K^U\right)}{\partial X_K^U} = 0. \tag{7}$$

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[4] The total cost function of the downstream stage holds irrespective of whether or not the two stages are integrated, because X_K^D does not appear in the upstream stage.

[5] Line losses are ignored here for explanatory simplicity. In our sample, line losses amount to around 5 percent of the electricity received from the upstream stage. Since this ratio is quite stable over the whole period of analysis, a presumption of no line losses is unlikely to affect empirical results of the analysis.

In contrast, a separately operated utility firm behaves on a stand-alone basis and cannot make centralized decisions. We assume that the wholesale market for electricity is fully competitive and that an upstream firm maximizes its profit given the price determined by the market. Then, we have the first order conditions of Y^U and X_K^U for an upstream firm as:

$$\frac{\partial VC^U\left(W_L^U, W_F^U, X_K^U, Y^U\right)}{\partial Y^U} = W_E^D, \tag{8}$$

and

$$\frac{\partial VC^U\left(W_L^U, W_F^U, X_K^U, Y^U\right)}{\partial X_K^U} + W_K^U = 0. \tag{9}$$

Here W_E^D is the wholesale electricity price.

On the other hand, a downstream firm is supposed to minimize its total cost given electricity demanded by ultimate consumers. Since a separated downstream firm has to buy electricity from the wholesale market, its total cost becomes $C^D + W_E^D X_E^D$. Then, the first order conditions of X_E^D for a downstream firm are:

$$\frac{\partial C^D\left(W_L^D, X_E^D, W_K^D, Y^D; X_K^U\right)}{\partial X_E^D} + W_E^D = 0. \tag{10}$$

It is easily verified that if $X_E^D = Y^U$, eqs. (8) and (10) are equivalent to eq. (6). Thus, vertically separated utility firms choose the optimal production of electricity $\tilde{Y}^U$ and the optimal generation capital $\tilde{X}_K^U$ by solving eqs. (6) and (9), while a vertically integrated firm determines them as $\hat{Y}^U$ and $\hat{X}_K^U$ by solving eqs. (6) and (7). Evaluating eq. (5) with $(\hat{Y}^U, \hat{X}_K^U)$ and $(\tilde{Y}^U, \tilde{X}_K^U)$, we have

$$C\left(W, \tilde{Y}^U, \tilde{X}_K^U, \tilde{Y}^U, Y^D\right) \geq C\left(W, \hat{Y}^U, \hat{X}_K^U, \hat{Y}^U, Y^D\right). \tag{11}$$

Eq. (11) holds because eq. (7) is a special case of eq. (9). If no technological externality through the generation facilities exists, eq. (7) reduces to eq. (9) because $\partial C^D / \partial X_K^U = 0$. Eq. (11) thus holds as an equality if and only if this is the case. In other words, any economies of vertical integration arise from the external effect of the generation facilities on the transmission-distribution network.

It should be noted that if an increase in generation facilities reduces downstream costs $(\partial C^D / \partial X_K^U < 0)$, a separated upstream firm retains capital short of the efficient level as long as the marginal productivity of X_K^U is decreasing. Conversely, if an increase in the generation facilities raises the downstream costs $(\partial C^D / \partial X_K^U > 0)$, a separated upstream firm holds excess capital. We do not maintain any hypothesis regarding the sign of $\partial C^D / \partial X_K^U$. Estimating the cost function of the downstream stage will contribute evidence on this point.

3. Empirical Model

This section presents the shadow cost function model to empirically examine the technological externality between upstream and downstream stages[6]. The neoclassical cost function assumes that a firm minimizes costs subject only to an output constraint. Nevertheless, a firm may have to take account of additional constraints imposed by its regulatory circumstances and incomplete adjustments of inputs to past changes in their prices. Especially in the electric utility industry, fixity of capital stocks and fair rate-of-return-based pricing require modifying the standard neoclassical

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[6] A more straightforward way to assess the technological externality is to estimate the production function (2). However, we prefer the cost function approach to avoid the multicollinearity that is likely to occur with a very high correlation between X_K^U and X_K^D. In fact, the correlation coefficient between them is 0.982 in our data set.

cost function.

Under rate-of-return regulation, the dual representation of a production function takes the form of a regulated cost function. Lasserre and Ouellette (1987) present a rate-of-return regulated cost function model where capital is a quasi-fixed input. Although this model seems to be suitable to our purpose, we cannot estimate it because data on the allowed rate-of-return are unavailable. Some previous studies obtain the allowed rate-of-return by assuming that the rate-of-return constraint is always binding. However, this assumption is not realistic in situations where regulatory lag enables a utility to earn profits above the allowed rate. Furthermore, even if no regulatory lag exists, a rate-of-return constraint is hardly satisfied in a vertically integrated utility which is the case in our sample. In a vertically integrated utility, capital stocks of the downstream stage represent only a part of the rate base input, whereas the regulatory constraint is applied to all of it. Thus, a rate-of-return regulated cost function cannot be applied to our analysis.

Keeping the above considerations in mind and taking account of other restrictions such as the requirements for environmental protection, we need a more flexible way of modeling the behavior of a utility faced with several constraints of unknown form. As a consequence, the shadow cost function approach initially proposed by Atkinson and Halvorsen (1984) is employed in this paper. This approach assumes that a firm bases its production decisions not on observed market prices but on unobservable shadow prices. Differences between the two prices are interpretable as the effects of constraints facing an electric utility.

Following Atkinson and Halvorsen, the shadow prices, W_i^* are assumed to deviate from the market prices, W_i as[7]:

$$W_i^{D^*} = d_i W_i^D, \ \ d_i > 0, \ \ i = L, E, K. \tag{12}$$

To the extent that the factors of proportionality, d_i, depart from unity, the behavior of a utility is allocatively distorted and inefficient. We further assume that the $d_i s$ depend on both a time trend and variables reflecting characteristics inherent in a firm, allowing them to be firm-specific and time-varying. Specifically,

$$\begin{aligned} d_E &= \left(1 + \phi_E + \phi_{Et} t + \phi_{Ett} t^2 + \phi_{EH1} H_1 + \phi_{EH2} H_2\right)^2, \\ d_K &= \left(1 + \phi_K + \phi_{Kt} t + \phi_{Ktt} t^2 + \phi_{KH1} H_1 + \phi_{KH2} H_2\right)^2, \end{aligned} \tag{13}$$

where t is a time trend representing the state of technology, and H_1 and H_2 are, respectively, the demand density and the line loss of power that are hedonic variables capturing the characteristics of each firm[8]. Here, d_L is normalized to be unity because not all d_is are identifiable, owing to the homogeneity of degree zero in input prices. The right hand sides of (13) are squared so that d_E and d_K are restricted to be nonnegative. If $d_E = d_K = 1$ or, in other words, if all parameters on the right hand sides of (13) are insignificant, the cost function reduces to the standard neoclassical cost function.

The empirical total cost function of the downstream stage is thus obtained by evaluating it with the shadow prices of inputs. Instead of eq. (4), we proceed with the

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[7] The shadow prices may be alternatively defined as additively related to the actual prices. It is, however, not easy to restrict the additively defined shadow prices to be positive. In the literature, a multiplicative definition is commonly used. Kumbhakar (1992) in particular shows that a multiplicative definition is conformable to the cost function of the symmetric generalized McFadden form which is used also in this paper.

[8] During the period of analysis, the regulation authority changed the book-value-based fair rate of return three times, in 1988, 1996 and 1998. We test the responsiveness of d_K to such changes using dummy variables. The results show that those dummies do not affect d_K at the 5 percent significance level, which also suggests the ineffectiveness of a rate-of-return regulation.

unconditional total cost function:

$$\begin{aligned} &C_O^D\left(W_L^D, W_E^D, W_K^D, Y^D; X_K^U\right) \\ &\quad = \min_{X_E^D}\left\{C^D\left(W_L^D, X_E^D, W_K^D, Y^D; X_K^U\right) + W_E^D X_E^D\right\}. \end{aligned} \tag{14}$$

Equation (14) is preferable to (4) because it avoids severe multicollinearity caused by a very high correlation between X_E^D and Y^D. Taking account of allocative distortions, we assume that the total cost is minimized not with respect to market prices but with respect to unobservable shadow prices W_i^*. Consequently, the following unconditional total cost function serves as a basis for empirical analysis:

$$C^{D^*} = C_O^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right), \tag{15}$$

where C^{D^*} is the shadow cost that differs from the actual total cost unless shadow prices coincide with market prices.

The demand equations for inputs are derived from applying the Shephard's lemma to (15):

$$X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right) = \frac{\partial C^{D^*}}{\partial W_i^*}, \quad i = L, E, K. \tag{16}$$

The actual total cost is then given by $\sum W_i X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right)$ which is not below the efficient level $\sum W_i X_i^D\left(W_L^D, W_E^D, W_K^D, Y^D; X_K^U\right)$.

Next, we employ the form of symmetric generalized McFadden (SGM) for specifying the cost function (15):

$$
\begin{aligned}
C^{D^*} = {} & g\left(W^{D^*}\right)Y^D + \sum_i b_i W_i^{D^*} + \sum_i b_{ii} W_i^{D^*} Y^D + a_{YY}\left\{\sum_i \alpha_{iYY} W_d^{D^*}\right\} Y^{D^2} \\
& + \sum_i b_{it} W_i^{D^*} Y^D t + a_t \left\{\sum_i \beta_{it} W_i^{D^*}\right\} t + a_h \left\{\sum_i \gamma_{ih} W_i^{D^*}\right\} H_1 \\
& + a_{gYt}\left\{\sum_i \delta_{igYt} W_i^{D^*}\right\} X_K^U Y^D t + a_{g2}\left\{\sum_i \lambda_{ig2} W_i^{D^*}\right\} X_K^{U^2},
\end{aligned}
\tag{17}
$$

$$
i = L, E, K,
$$

where $W^{D^*} = \left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}\right)^{\mathrm{T}}$ and the function $g(\cdot)$ is defined by

$$
g\left(W^{D^*}\right) = W^{D^{*\mathrm{T}}} S W^{D^*} \Big/ 2\theta^{\mathrm{T}} W^{D^*}. \tag{18}
$$

For $\theta = (\theta_L, \theta_E, \theta_K)^{\mathrm{T}}$, the average values of X_L^D, X_E^D, and X_K^D during the period of analysis are assigned, respectively. The 3×3 matrix S is symmetric and negative semi-definite so that the cost function is globally concave in the shadow prices. If the estimated parameters do not imply negative semi-definiteness of S, it can be imposed on S by taking the reparameterization of $S = -AA^{\mathrm{T}}$ where A is a lower triangular matrix. The sum of each row in S is also constrained to zero to meet the adding up condition, i.e., $\sum_i S_{ij} = 0$ for all j where S_{ij} is the $i-j$ element of S.

The remarkable feature of the SGM form is that flexibility is not sacrificed by global concavity[9]. In fact, eq. (17) is sufficiently rich in parameters to satisfy flexibility irrespective of whether a negative semi-definiteness of S is imposed. We normalize a_{YY}, a_t, a_h, a_{gYt}, and a_{g2} to unity to simplify the estimation equations,

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[9] See Diewert and Wales (1987) for details. Using the translog form, we fail to obtain acceptable results satisfying the regularity conditions. As is known, it is not desirable to impose global concavity on the translog cost function since the parameter restrictions destroy its flexibility. The SGM provides an appropriate alternative for our purposes.

leaving the parameters α_{iYY}, β_{it}, γ_{ih}, δ_{igYt}, and λ_{ig2}, $i = L,E,K$ to be estimated[10]. Despite such simplifications, the cost function still meets the condition of the numerical flexibility discussed by Diewert (1974)[11].

The input demand equations (16) take the form of

$$\begin{aligned}\frac{X_i^D}{Y^D} &= \left\{\frac{S^{(i)}W^{D^*}}{\theta^{\mathrm{T}}W^{D^*}} - \frac{\theta_i}{2}\frac{W^{D^{*\mathrm{T}}}SW^{D^*}}{\left(\theta^{\mathrm{T}}W^{D^*}\right)^2}\right\} + b_i/Y^D + b_{ii} + \alpha_{iYY}Y^D + b_{it}t + \beta_{it}t/Y^D \\ &\quad + \gamma_{ih}H_1/Y^D + \delta_{igYt}X_K^U t + \lambda_{ig2}X_K^{U2}/Y^D + u_i, \qquad (19) \\ &\quad i = L,E,K,\end{aligned}$$

where $S^{(i)}$ is the *i*th row of the S matrix and $u = (u_L, u_E, u_K)^{\mathrm{T}}$ is assumed to be identically and independently distributed with zero mean and a constant covariance matrix. Both sides of (16) are divided by output Y^D to wipe out heteroscedastic effects in the error term. To make elasticity estimates invariant, the θ_i are set equal to the mean values of inputs over the entire sample.

The presence of a technological externality is examined by testing the sensitivity of the transmission-distribution cost to generation capital. For this purpose, we measure the elasticity of cost with respect to generation capital as $\left(X_K^U/C^{D^*}\right)\left(\partial C^{D^*}/\partial X_K^U\right)$, where

$$\partial C^{D^*}/\partial X_K^U = \left\{\sum_i \delta_{igYt}W_i^{D^*}\right\}Y^D t + 2\left\{\sum_i \lambda_{ig2}W_i^{D^*}\right\}X_K^U. \qquad (20)$$

If $\delta_{igYt} = \lambda_{ig2} = 0$, $i = L,E,K$, no technological externality exists, and thus an electric utility firm experiences no economies of vertical integration.

The effects of allocative distortions on the use of individual inputs are

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[10] The same normalization is taken by Kumbhakar (1992).

[11] See Kumbhakar (1994) for a proof.

evaluated by a difference in input demands with and without allocative distortions as:

$$\eta_i = \frac{X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right) - X_i^D\left(W_L^D, W_E^D, W_K^D, Y^D; X_K^U\right)}{X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right)}, \qquad (21)$$

$$i = L, E, K.$$

The overall effects of allocative distortions are evaluated by the amount that cost could be reduced without any distortions. We calculate this as:

$$\rho = \frac{\sum W_i^D X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right) - \sum W_i^D X_i^D\left(W_L^D, W_E^D, W_K^D, Y^D; X_K^U\right)}{\sum W_i^D X_i^D\left(W_L^{D^*}, W_E^{D^*}, W_K^{D^*}, Y^D; X_K^U\right)}. \qquad (22)$$

4. Empirical Results

4.1. Data

The data set consists of annual observations during the 1981-1998 period on the downstream stage of nine Japanese electric utility firms: Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku and Kyushu. They are all privately owned and vertically integrated companies. Data on the price and quantity of three inputs, labor, purchased electricity and capital, are necessary. The prices for these inputs are constructed in a way that the cost for each input is divided by the corresponding quantity.

The cost of capital includes expenses of depreciation, maintenance and interest payments. The interest payment of the downstream stage is calculated by multiplying the firm’s total interest payments by the share of acquisition costs of the downstream stage. Capital stocks are constructed by the perpetual inventory method used by Cowing *et al.* (1981). The benchmark capital stocks are obtained by converting the book values at the base year, 1980, with a triangularized weighted average of the capital stock price indexes.

Labor is specified as the number of employees. The price of labor is thus obtained by dividing labor expenses by the number of employees.

Electricity input is defined as the sum of electricity purchased from other firms as well as electricity received from the generation stage of the same firm. Its price is calculated by unit value of the purchased price, i.e., expenses for the purchased electricity divided by its quantity.

4.2. Estimation Results

The system of input demand equations (19) together with (13) is then estimated by using the iterative seemingly unrelated regression technique. The parameter estimates are reported in Table 1. The concavity of the cost function is globally satisfied since negative semi-definiteness is imposed on the Slutsky matrix S. Monotonicity in inputs and nonnegativity of costs are satisfied at each one of the observations.

Insert Table 1 near here.

We begin by examining the technological externality of generation capital. The null hypothesis of $\delta_{igYt} = \lambda_{ig2} = 0,\ i = L, E, K$ is decisively rejected at the 1 percent significance level by the Wald test. Thus, it follows from eq. (20) that the transmission-distribution cost depends on the generation capital, suggesting economies of vertical integration.

Insert Table 2 near here.

Table 2 presents the estimated elasticity of cost with respect to the generation capital. In the upper panel, the elasticity of cost with allocative distortions based on estimated d_E and d_K is shown for each electric utility firm in the years selected. The positive values of elasticity imply that the more generation plants join the network, the higher are the costs incurred in the transmission-distribution stage. Thus, the generation stage will inefficiently overcapitalize from the perspective of the social optimum if it is separated from the transmission-distribution stage. These external diseconomies are internalized by vertical integration that enables centralized decision making over all stages[12].

However, it should be noted that the above results are not purely technological since the elasticity of cost varies with the allocative distortions. Färe and Logan (1986) show that, in the context of rate-of-return regulation, measurements of some economic concepts heavily rely on whether the cost function is conditional on the regulatory parameter[13]. We thus examine the magnitude of the external effects without allocative distortions by evaluating the elasticity of cost at $d_E = d_K = 1$. The results are shown in the lower panel in Table 2. Although removing allocative distortions does not make much difference, the effects of the technological externality are a little greater without such distortions for several electric utility firms, providing evidence that the allocative distortions are able to mask external diseconomies.

In both panels, the elasticity of cost exhibits an increasing trend. This is

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[12] Since an increase in the electricity supply lowers the wholesale price, the cost of the transmission-distribution stage is likely to be reduced by an expansion of generation capital. This is another linkage between C^D and X_K^U that is difficult to separate from the technical externality we discuss here. However, while this effect predicts a negative relationship between C^D and X_K^U, the detected relationship is in fact a positive one. Thus, one thing is at least certain, i.e., external diseconomies of generation capital exist in the transmission-distribution stage, though their magnitude is possibly overestimated.

[13] Färe and Logan find a way to recover pure technological parameters from the rate-of-return regulated cost function, and illustrate it with an application to the regulated cost function of the U.S. electric utilities estimated in Nelson and Wohar (1983). Their results indicate that the elasticities of substitution are dramatically changed by removing the regulatory effects.

attributable to a rapid growth in generation capacity and a resulting congestion of the transmission network. During the 1981-1998 period in Japan, the generation capacity X_K^D grew much faster than the transmission network, so that while the transmission cost C^{D^*} was relatively stable, X_K^U / C^{D^*}, and thereby the elasticity increased substantially. Furthermore, since λ_{ig2}, $i = L, E, K$ are all estimated to be positive, it follows from eq. (20) that the second derivative, $\partial^2 C^{D^*} / \partial \left(X_K^U\right)^2$, is positive. Thus, the growth of generation capacity makes the elasticity of cost greater. This implies congestion of the transmission network in the sense that the costs of installing new generation plants on the network is increasing with generation capacity, given the size of the network.

Besides the generation plants, we tested in a similar way whether the other inputs in the generation stage cause technological externalities. Our results indicate that the amount of fuel in the generation plants affects costs of the transmission-distribution stage while labor input causes no externality. Since fuels are closely linked to generation plants, the relationship detected here is considered to be consistent with the technological externality arising from these plants.

Another issue of interest is allocative distortions. Applying the Wald test, we confirmed that the discount factors, d_E and d_K, are significantly different from unity at the 1 percent significance level on all observations in the sample. These electric utility firms thus fail to efficiently use inputs in the transmission-distribution stage, which invalidates the adequacy of the standard neoclassical cost function model.

Insert Figure 1 near here.

Figure 1 shows the behavior of d_E and d_K on average for nine electric utility firms over the 1981-1998 period. As shown, d_E ranges from 1.2 to 1.8 with an increasing trend while d_K keeps below unity except 1998 with a similar trend to d_E. This implies that the electric utility firms in our sample tend on average to over-utilize capital and under-utilize electricity input relative to labor. Capital is also over-utilized relative to electricity input because the ratio of d_K / d_E is less than unity over the whole period.

Insert Table 3 near here.

Table 3 presents the effects of allocative distortions on the use of individual inputs. The mean, maximum and minimum values of the degree of misuse in inputs, η_i, $i = L, E, K$, are shown for each electric firm. If η_i is positive (negative), then the *i*th input is over-utilized (under-utilized). It can be generally seen that the three largest firms, Tokyo, Kansai and Chubu, over-utilize capital and under-utilize labor, while the other firms under-utilize capital and over-utilize labor. The magnitudes of misuse in electricity input are somewhat smaller than those of labor and capital, indicating that electricity input is more variable than the other inputs.

Insert Table 4 near here.

Table 4 presents the overall effects of allocative distortions in terms of cost that could be saved without distortions. The ratio of the reducible cost to the actual cost is shown for each electric utility firm in selected years. As shown, they range from 0.13 to 2.97 percent on average. Tokyo, Kansai and Chubu, operating in the three largest metropolitan areas in Japan, are relatively efficient. This is plausible since higher demand density due to a high population consumer base makes their transmission-distribution network more efficient. However, the most efficient firm is Hokuriku of which the rate of reducible cost is no more than 0.24 percent. Hokuriku is the smallest firm so that its demand density is not very high. Nevertheless, unlike the other eight firms, it is almost free of the location problem of nuclear plants that are forced to construct longer lines to supply power to remote urban areas.

5. Conclusions

This paper has examined economies of vertical integration in the electricity sector, focusing on the technological linkage between the generation and transmission-distribution stages. A shadow cost function of the symmetric generalized McFadden form is estimated using data on the transmission-distribution stage of nine Japanese electric utility firms. Our results confirm the existence of economies of vertical integration claimed by many previous studies including Kaserman and Mayo (1991), Gilsdorf (1994,1995), Lee (1995) and Hayashi et al. (1997). We have found that generation capital adversely affects the cost of the transmission-distribution stage as if it were a negative public input. Therefore, unless the electric utility firms are vertically separated, generation capital tends to be excessive from the perspective of the social optimum.

Furthermore, plausible estimates on the degree of allocative distortions were obtained. The potential rate of cost savings is estimated to be 0.13-2.97 percent on average for each electric utility firm. Our results reject the applicability of the neoclassical minimum cost function, which illustrates the importance of controlling for allocative distortions in any empirical analysis.

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Table 1: Estimated results of the cost function

Parameter	Estimates (*t* Ratio)	Parameter	Estimates (*t* Ratio)	Parameter	Estimates (*t* Ratio)	Parameter	Estimates (*t* Ratio)
S_{LL}	-1.35E-03 (-3.44)**	ϕ_{EH2}	-1.6113 (-4.87)**	b_{EE}	0.6969 (152.17)**	α_{KYY}	-0.0141 (-2.57)**
S_{LE}	-1.66E-03 (-9.54)**	ϕ_{K}	0.1078 (0.22)	b_{KK}	0.1826 (15.38)**	γ_{Lh}	-9.19E-03 (-3.75)**
S_{EE}	-3.38E-03 (-5.06)**	ϕ_{Kt}	-2.25E-04 (-0.03)	b_{Lt}	-1.68E-03 (-6.57)**	γ_{Eh}	0.0123 (2.72)**
S_{LK}	3.01E-03 (5.75)**	ϕ_{Ktt}	1.24E-03 (3.19)**	b_{Et}	-8.68E-04 (-4.20)**	γ_{Kh}	-0.0853 (-8.36)**
S_{EK}	5.04E-03 (6.79)**	ϕ_{KH1}	-1.4238 (-3.38)**	b_{Kt}	3.27E-03 (3.48)**	δ_{LgYt}	-3.03E-03 (-5.51)**
S_{KK}	-8.05E-03 (-8.49)**	ϕ_{KH2}	0.8161 (4.36)**	β_{Lt}	-3.38E-05 (-0.36)	δ_{EgYt}	-4.23E-03 (-8.04)**
ϕ_{E}	3.7107 (3.99)**	b_{L}	6.18E-03 (2.81)**	β_{Et}	3.56E-04 (4.76)**	δ_{KgYt}	-0.0162 (-6.45)**
ϕ_{Et}	-4.54E-04 (-0.05)	b_{E}	-0.0124 (-3.66)**	β_{Kt}	8.87E-04 (2.17)*	λ_{Lg2}	0.2447 (9.26)**
ϕ_{Ett}	1.05E-04 (0.21)	b_{K}	0.0552 (7.22)**	α_{LYY}	-8.05E-03 (-6.09)**	λ_{Eg2}	0.3144 (12.04)**
ϕ_{EH1}	-3.4513 (-4.82)**	b_{LL}	0.0649 (20.91)**	α_{EYY}	3.10E-03 (2.25)*	λ_{Kg2}	1.3282 (10.50)**

Note) ** and * indicate that the estimated coefficients are significant at the 1% and 5% level, respectively.

t Ratios in parentheses are computed from a heteroscedastic-consistent matrix by White’s method.

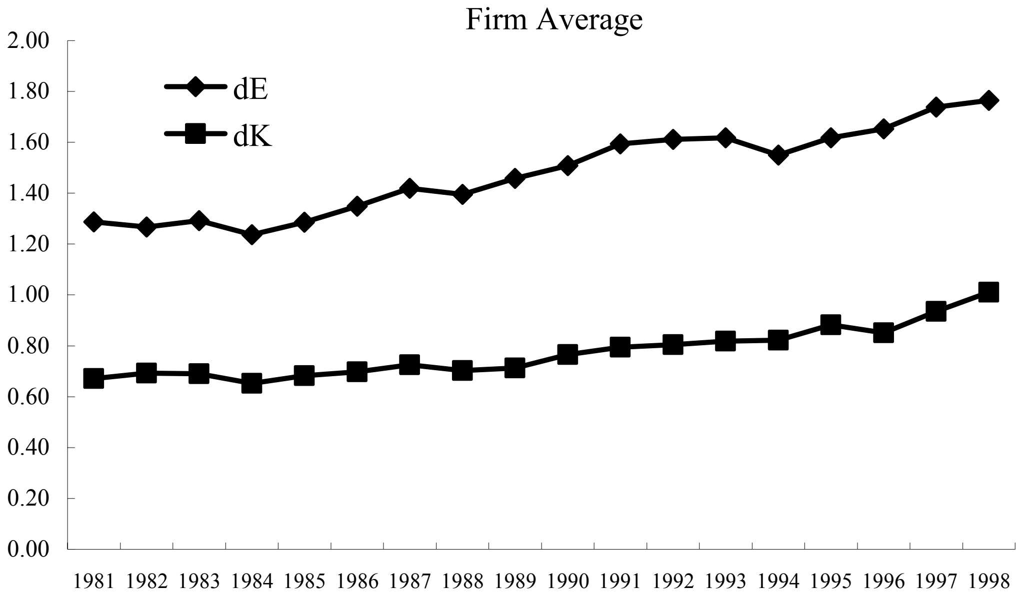

Figure 1: Development of distortion factors over time

Table 2: Elasticity of cost in the downstream stage with respect to generation capital

With allocative distortion

Firm/Year	1981	1985	1989	1993	1998	average
Hokkaido	0.0454	0.1008	0.1966	0.2384	0.2423	0.1642
Tohoku	0.0183	0.0526	0.0429	0.0616	0.2056	0.0697
Tokyo	0.0786	0.3461	0.5168	0.8061	1.3262	0.6180
Chubu	0.0134	0.0171	0.0505	0.1046	0.2206	0.0727
Hokuriku	0.0110	0.0123	0.0121	0.0593	0.1078	0.0380
Kansai	0.0936	0.2552	0.3247	0.6061	0.8230	0.4173
Chugoku	0.0118	0.0136	0.0734	0.1157	0.1895	0.0771
Shikoku	0.0300	0.0578	0.0656	0.0610	0.1214	0.0763
Kyushu	0.0236	0.0888	0.1588	0.2608	0.4081	0.1769
average	0.0362	0.1049	0.1602	0.2571	0.4049	0.1900

Without allocative distortion

Firm/Year	1981	1985	1989	1993	1998	average
Hokkaido	0.0350	0.0929	0.1744	0.1927	0.1958	0.1404
Tohoku	0.0165	0.0472	0.0383	0.0525	0.1542	0.0576
Tokyo	0.0865	0.3287	0.4572	0.5602	0.7914	0.4495
Chubu	0.0463	0.0550	0.1493	0.2662	0.4357	0.1791
Hokuriku	0.0220	0.0237	0.0231	0.0956	0.1386	0.0596
Kansai	0.0696	0.1901	0.2428	0.3898	0.4068	0.2664
Chugoku	0.0222	0.0239	0.1152	0.1415	0.1970	0.0994
Shikoku	0.0469	0.0747	0.0763	0.0608	0.0991	0.0791
Kyushu	0.0417	0.1565	0.2279	0.3259	0.4266	0.2250
average	0.0430	0.1103	0.1672	0.2317	0.3161	0.1729

Table 3: Effects of allocative distortions on individual inputs (η_i) %

Firm/Input	Labor			Electricity			Capital		
	ave.	max.	min.	ave.	max.	min.	ave.	max.	min.
Hokkaido	14.93	17.45	12.53	4.94	7.18	3.01	-6.21	-4.92	-8.41
Tohoku	9.11	13.93	3.84	1.69	2.34	0.89	-4.29	-3.01	-5.15
Tokyo	-5.40	-3.57	-6.59	-0.30	-0.10	-0.49	3.18	6.34	1.39
Chubu	-7.20	-1.22	-11.49	0.73	1.16	0.16	2.34	4.96	-0.27
Hokuriku	0.99	4.05	-1.21	0.43	0.99	0.16	-1.31	0.03	-3.68
Kansai	-4.65	-2.58	-5.95	-0.26	-0.06	-0.48	3.58	7.20	1.28
Chugoku	7.81	13.83	2.63	1.86	2.99	0.74	-4.06	-2.47	-5.08
Shikoku	14.00	20.04	5.57	3.82	4.85	2.14	-6.61	-4.87	-8.00
Kyushu	4.74	8.34	2.20	1.41	3.08	0.58	-2.97	-1.43	-6.58

Table 4: Overall effects of allocative distortions in terms of cost (ρ) %

Firm/Year	1981	1985	1989	1993	1998	average
Hokkaido	4.28	3.41	2.71	3.02	2.48	2.97
Tohoku	0.63	1.00	0.54	0.67	0.71	0.74
Tokyo	0.56	0.39	0.38	0.21	0.11	0.31
Chubu	0.50	0.54	1.10	0.93	0.93	0.77
Hokuriku	0.21	0.15	0.08	0.12	0.24	0.13
Kansai	0.50	0.37	0.32	0.18	0.07	0.27
Chugoku	0.52	0.88	0.37	1.11	1.42	0.81
Shikoku	0.70	2.24	1.99	2.07	2.31	2.19
Kyushu	1.47	0.53	0.33	0.25	0.41	0.55
average	1.04	1.06	0.87	0.95	0.97	0.97