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Economies of Scale and Scope in Australian Telecommunications

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Abstract. This paper employs a composite cost function to examine the cost structure of Australian telephone services. The composite cost model combines the log-quadratic input price structure of the translog model with a quadratic structure for multiple outputs. Quadratic output structures permit the measurement of economies of scale, economies of scope, and subadditivity without prejudging their presence. Model estimates, on Telstra system data from 1926 to 1991, show that the production of Australian telephone services exhibits economies of scope but no ray economies of scale.

Key words: Telecommunications, production, scale, scope, Australia

I. Introduction

Since the early part of this century the telephone industry has been organised as a natural monopoly under the assumption that its cost structure is subadditive. When a firm's cost function is subadditive (for given input prices) it can produce an arbitrary output vector more cheaply than any two firms faced with same cost function (Baumol and Braunstein, 1977). Subaddivity can arise from economies of scale and/or economies of scope. However, economies of scale are neither necessary nor sufficient for subadditivity, while economies of scope are necessary. Economies of scale exist when the marginal costs of production are less than ray average cost over the relevant output range. Economies of scope exist when common facilities make the production of a combination of goods less expensive then producing them separately. As single firm production is the more cost effective in producing any output mix, monopolistic firms are usually subject to price and entry regulation in an attempt to achieve competitive outcomes (Berg and Tschirhart, 1995).

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Received telecommunications cost studies typically employ the translog cost function when examining economies of scale and scope. The translog model places no *a priori* restrictions on substitution possibilities among production inputs, and allows scale economies to vary with the level of output (Christensen and Greene, 1976). A criticism of the translog function is its poor global approximation ability, especially when the true cost structure is different from the Cobb–Douglas form (not surprising since the translog pivots off the Cobb–Douglas). Röller (1990a) argues that complex multiproduct cost properties, such as economies of scope or subadditivity, should not be modeled with a translog function. The cost function is degenerate at zero output levels.[1]

Pulley and Braunstein (1992) propose an alternative model for the indirect cost function of multiproduct technology. The composite cost function combines the log-quadratic input price structure of the translog model with a quadratic structure for multiple outputs. Further, the model is easily constrained to be linear homogeneous in input prices, and does not impose separability or other restrictions. Baumol et al. (1988) recommend the quadratic output structure for its ability to measure economies of scope, product-specific economies of scale and subadditivity without prejudging their presence.

This paper examines the Australian telecommunications cost structure for the period 1926 through 1991. A composite cost function is estimated and empirical testing for economies of scale and scope is performed. The paper is organised as follows. Section II describes the data and econometric model used to estimate the multi-product composite cost function. Estimation results are reported in Section III, and an empirically tractable test for local subadditivity is presented in Section IV. Concluding remarks are provided in Section V.

II. Econometric Model and Data

Econometric studies of telecommunications costs either aggregate services into a single measure of output (and estimate single-product cost functions) or enter outputs separately into a cost function. Baumol et al. (1988) argue that using a multiproduct cost function is appropriate, as employing a weighted single measure of output $Y = \Sigma_i a_i y_i$ implicitly requires $C(y_1, \ldots, y_m) = C(Y) = C(\Sigma_i a_i y_I)$. This restriction on the functional form of the cost function is unlikely to be met, and so must induce bias.

Estimation with separate outputs involves the specification of a composite cost function.[2] This can be used to measure the costs of specialised production, as is

[1] It is not the estimated price effects that deteriorate away from the approximation point, but rather the estimates of the output effects (Diewert and Wales, 1991).

[2] The ability to model cost behaviour in the range of zero outputs gives it an advantage over the translog and generalised translog forms. And by not imposing separability, the composite cost function improves upon the CES-Quadratic form of Röller (1990b).

required for estimating economies of scope. The composite cost function is written as:

$$\begin{aligned}\ln C \;=\; & \ln[\alpha_0 + \alpha_i q_I + \frac{1}{2}\Sigma_i \Sigma_j \alpha_{ij} q_i q_i + \Sigma_i \Gamma_i T q_i + \Phi_1 T + \frac{1}{2}\Phi_2 T^2 \\ & + \Sigma_i \Sigma_K \delta_{iK} q_i \ln r_K] + \Sigma_K \beta_K \ln r_K + \frac{1}{2}\Sigma_K \Sigma_L \beta_{KL} \ln r_K \ln r_L \\ & + \Sigma_K \Omega_K \ln T \ln r_K + \lambda T75, \end{aligned} \tag{1}$$

where q_i $(i = 1, \ldots, m)$ refers to outputs, r_K $(K = 1, \ldots, n)$ refers to input prices, and T is technology change. To account for the 1975 separation of the Postmaster-General's Department (PMG) into Australia Post and Telecom Australia, respectively, $T75$ equals one for $t > 1975$, and zero otherwise. All variables are divided by their respective sample means.

By Shephard's Lemma $x_n = \partial c / \partial r_n$, Where x_n is the input demand for the nth factor. The cost share equations ($S_n = r_n x_n / C$) corresponding to (1) are:

$$\begin{aligned} S_n \;=\; & [\alpha_0 + \Sigma_i \alpha_i q_i + \frac{1}{2}\Sigma_i \Sigma_j \alpha_i q_i q_j + \Sigma_i \Gamma_i T q_i + \Phi_1 T \\ & + \frac{1}{2}\Phi_2 T^2 + \Sigma_i \Sigma_K \delta_{iK} q_i \ln r_K]^{-1} \\ & + \Sigma_i \delta_{in} q_i + \beta_n + \Sigma_K \beta_{Kn} \ln r_K + \Omega_K \ln T, \end{aligned} \tag{2}$$

where $n = K, L$. The input price homogeneity (of degree one) restrictions are $\Sigma_K \beta_K = 1$, $\Sigma_K \beta_{KL} = 0$, $\Sigma_K \delta_{iK} = 0$, $\Sigma_K\ \Omega_K = 0$. Symmetry restrictions are $\alpha_{ij} = \alpha_{ji}$ and $\beta_{KL} = \beta_{LK}$.

Annual data on costs, input prices, and output quantities are obtained from the Australian Bureau of Statistics (ABS), Australia Post, PMG, and Telecom Australia annual reports. Long-run cost (C) is the total cost of producing telephone services. Telecommunications services are measured by millions of local (q_{LO}) and toll (long-distance) calls (q_T).[3] Productive factors are labour and capital. The price of labour (w_L) is total salary expense divided by the number of employees. Capital price (w_K) is calculated from residual expenses (total cost less labour expenses), divided by mainlines. Exogenous technical change is measured by a time trend.[4] Summary statistics are provided in Table I.

[3] We acknowledge non-core outputs such as directory assistance, however, such services make up a relatively small share of total revenue.

[4] The cost function specification can use several measures of technical change. Endogenous measures, such as the percentage of telephones with access to direct dial facilities, and the percentage of mainlines connected to automatic exchanges can be included in the cost model in output-augmenting form. Denny et al. (1981) suggest that the introduction of direct dial facilities (such as STD) influences the provision of toll services, whilst the introduction of modern switching facilities at central exchange offices has its major impact on the provision of local services. The effect of such innovations is to reduce the cost of providing a given level of service, but the impact is service specific.

Table I. Summary statistics

		Mean	Std. dev.	Max	Min
Cost ($m)	C	1100	2017	7906	13
Local calls (m)	q_{LO}	2448	2437	9446	300
Toll calls (m)	q_T	311	462	1832	23
Labour price ($)	w_L	5991	8737	32163	384
Capital price ($)	w_K	105	169	647	6.60
Capital share	S_K	0.34	0.13	0.66	0.16
Labour share	S_L	0.66	0.13	0.84	0.34

III. Econometric Result

The cost function and the labour share equation are jointly estimated by a non-linear seemingly unrelated regression estimation (SURE) technique using annual data from 1926 to 1991. Since the factor shares sum to one, the capital share equation is deleted to obtain a nonsingular covariance matrix. Model estimation allows for first-order autocorrelation in each equation. SURE estimation results are reported in Table II.

Of the 16 estimated coefficients, ten are significant at the five percent level. The first-order terms for the independent variables, with the exception of toll output, are significant at the 1% level. The estimated coefficients for labour price and local output are positive and of plausible magnitude. The second-order output coefficients are not extraordinarily large. These estimates contrast with those of Evans and Heckman (1984), Charnes et al. (1988), Bloch et al. (1998) and Serafica (1998), which have absolute values in the range of four to ten. Large second-order output elasticities imply a percent increase in output causes an implausibly large change in the output cost elasticity, and suggest inferences of economies of scale and scope must be fragile (Shin and Ying, 1992; Braunstein and Pulley, 1998). Further, the time-local output negative interaction term suggests that technology reduces the cost of local calling.

For labour input price, the cost elasticity or factor share is positive, with a plausible magnitude. The labour input share is 0.66. The interaction term of labour price with time reveals a tendency for the labour share to decrease over time (technology is labour saving). The technology variable (time trend) is negative or cost saving, and highly significant at -0.9715. The positive second-order parameter indicates that these gains diminish through time. Finally, the dummy variable ($T75$), denoting the 1975 separation of the PMG into Australia Post and Telecom Australia, has a negative coefficient, which suggests the separation resulted in lower costs of telephony provision.

Table II. Estimation results

Variable	Parameter	t-ratio
Constant	1.383	7.585
Local	1.165	4.077
Toll	0.087	0.331
Local × local	1.532	1.149
Toll × toll	0.280	0.725
Local × toll	0.093	0.136
Technology × local	−1.919	−2.560
Technology × toll	−0.047	−0.107
Technology	−0.972	−4.438
Technology × technology	3.661	6.279
Local × labour price	0.076	2.691
Toll × labour price	0.021	1.162
Labour price	0.690	25.202
Labour price × labour price	0.181	21.306
Technology × labour price	−0.063	−6.265
$T75$	−0.024	−2.878
Log-likelihood		384.118
Cost function	R^2	0.9998
Labour share	R^2	0.9959

IV. Economies of Scale and Scope

Before discussing economies of scale and scope, the regularity conditions for the estimated composite cost function are considered. Linear homogeneity in input prices and symmetry are imposed *a priori* during estimation, whilst continuity follows from the functional form. Since $\exp(\ln(C(q)))$ is strictly positive for all q, the estimated production costs are positive for all q. The marginal cost with respect to outputs are nonnegative, and the costs of production are nondecreasing in input price. By assumption, the input price is strictly positive, and output is strictly positive. The first-order partial derivative of the estimated composite cost function is positive when:

$$\partial \ln C/\partial \ln q_i = \alpha_i + \Sigma_j \alpha_{ij} \ln q_j + \Gamma_I \ln T + \Sigma_K \delta_{iK} \ln r_K \geq 0 \quad \text{for all } i \tag{3}$$

and

$$\partial \ln C/\partial \ln r_k = \beta_K + \Sigma_K \beta_{KL} \ln r_K + \Omega_K \ln T + \Sigma_i \delta_{iK} \ln q_i \geq 0 \quad \text{for all } K. \tag{4}$$

Substitution of cost function estimates and sample observations into (3) and (4), respectively, reveals that none of the 66 observations have negative marginal costs and costs are increasing with input prices. The final regularity condition is that the cost function is concave in input prices. Following Diewert and Wales (1987), we show that the cost function is concave in input prices since the matrix:

$$\Gamma(q) \equiv \begin{bmatrix} \beta_{LL} - S_L^*(1 - S_L^*) & \beta_{LK} + S_L^* S_K^* \\ \beta_{KL} - S_K^* S_L^*) & \beta_{KK} - S_K^*(1 - S_K^*) \end{bmatrix}, \tag{5}$$

is negative definite (where * indicates the estimated cost shares). By satisfying the above conditions, the cost function is proper according to Röller (1990b).

Baumol (1977) and Baumol and Braunstein (1977) show a cost function is strictly subadditive at output vector q* when the function exhibits strictly declining ray-average costs (RAC) for $q \leq q^*$, and is trans-ray convex (TRC) along at least one cross-section through q^*. RACs are strictly declining at q^* (implying ray economies of scale) when:

$$\partial C(tq^*, r)/\partial t < (C(tq^*, r), \tag{6}$$

where $t = 1$. The estimated composite cost function exhibits strictly declining RACs when:

$$\text{RAC} = \alpha_0 + \Phi T + \frac{1}{2}\phi T^2 - \frac{1}{2}\Sigma_i \Sigma_j \alpha_{ij} q_i q_j > 0 \quad \text{for all } q \leq q^*. \tag{7}$$

A cost function is TRC convex through q when there exists one trans-ray cross-section through q along which the cost function is convex. For the two output case, trans-ray convexity can be examined by considering the locus $q_2 = -aq_1 + b$, with $a > 0$.

Following this substitution, trans-ray convexity is implied by:

$$\partial^2 C(q_1, -aq_1 + b, r)/\partial q_1^2 > 0, \tag{8}$$

for $a > 0$. The composite cost function will be TRC along one cross-section through q^* when:

$$\text{TRC} = \alpha_{11} - 2\alpha_{12} a + \alpha_{22} a^2 > 0 \quad \text{for some } a > 0. \tag{9}$$

As noted by Braunstein and Pulley (1998) the TRC condition depends only on the estimated coefficients and an arbitrary positive parameter. As such, it is possible to examine the TRC condition globally. The RAC condition, however, depends on values of the variables and coefficient estimates, and cannot be established globally. To implement an empirically tractable test for economies of scale, RAC behaviour is simulated over three different output paths from the actual output values in a given year. Along path q^1, both q_{LO} and q_T are scaled down to zero in 0.1 increments. Along paths q^2 and q^3, one of the outputs is fixed at its actual value and the other output is scaled down to zero.

Table III. Economies of scale and scope simulations, 1959

$q^1 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$		$q^2 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$		$q^3 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$	
(α_{LO}, α_T)	RAC condition	(α_{LO}, α_T)	RAC condition	(α_{LO}, α_T)	RAC condition
(1.0, 1.0)	−1474733	(1.0, 1.0)	−1474733	(1.0, 1.0)	−1474733
(0.9, 0.9)	−1194149	(1.0, 0.9)	−1195981	(0.9, 1.0)	−1472742
(0.8, 0.8)	−943101	(1.0, 0.8)	−946405	(0.8, 1.0)	−1470794
(0.7, 0.7)	−721587	(1.0, 0.7)	−726005	(0.7, 1.0)	−1468889
(0.6, 0.6)	−529609	(1.0, 0.6)	−534780	(0.6, 1.0)	−1467026
(0.5, 0.5)	−367166	(1.0, 0.5)	−372730	(0.5, 1.0)	−1465206
(0.4, 0.4)	−234258	(1.0, 0.4)	−239855	(0.4, 1.0)	−1463429
(0.3, 0.3)	−130885	(1.0, 0.3)	−136157	(0.3, 1.0)	−1461694
(0.2, 0.2)	−57047	(1.0, 0.2)	−61633	(0.2, 1.0)	−1460003
(0.1, 0.1)	−12744	(1.0, 0.1)	−16285	(0.1, 1.0)	−1458354
(0.0, 0.0)		(1.0, 0.0)	−112	(0.0, 1.0)	−1456747
TRC condition at a = 1 is 1.63					

Table IV. Economies of scale and scope simulations, 1991

$q^1 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$		$q^2 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$		$q^3 = (\alpha_{LO}q_{LO}, \alpha_T q_T)$	
(α_{LO}, α_T)	RAC condition	(α_{LO}, α_T)	RAC condition	(α_{LO}, α_T)	RAC condition
(1.0, 1.0)	−70279880	(1.0, 1.0)	−70279880	(1.0, 1.0)	−70279880
(0.9, 0.9)	−56925200	(1.0, 0.9)	−57154701	(0.9, 1.0)	−70034803
(0.8, 0.8)	−44976276	(1.0, 0.8)	−45394722	(0.8, 1.0)	−69799126
(0.7, 0.7)	−34433108	(1.0, 0.7)	−34999944	(0.7, 1.0)	−69572849
(0.6, 0.6)	−25295695	(1.0, 0.6)	−25970366	(0.6, 1.0)	−69355973
(0.5, 0.5)	−17564038	(1.0, 0.5)	−18305989	(0.5, 1.0)	−69148497
(0.4, 0.4)	−11238137	(1.0, 0.4)	−12006813	(0.4, 1.0)	−68950422
(0.3, 0.3)	−6317992	(1.0, 0.3)	−7072838	(0.3, 1.0)	−68761748
(0.2, 0.2)	−2803603	(1.0, 0.2)	−3504063	(0.2, 1.0)	−68582474
(0.1, 0.1)	−694969	(1.0, 0.1)	−1300490	(0.1, 1.0)	−68412600
(0.0, 0.0)		(1.0, 0.0)	−462116	(0.0, 1.0)	−68252127
TRC condition at a = 1 is 1.63					

Tables III and IV report RAC and TRC simulations for economies of scale and scope where the declining RAC condition is evaluated at 1959 (the midpoint of the sample) and 1991, respectively. The TRC condition is calculated for $a = 1$. A negative value indicates that (7) fails to hold and the composite function does not exhibit ray economies of scale (does not possess declining ray average costs). However, condition (9) holds and the production of Australian telephone services exhibits economies of scope.

Conclusions

This paper examines the Australian telecommunications sector from 1926 through 1991. Cost function specifications are described, as are tests for natural monopoly. Econometric results reported herein indicate that the cost structure for Australian telephone services was not subadditive over the sample period.

Thus, there is evidence to support having a monopoly supplier of telephone calls in Australia up to 1991. It remains to be determined whether this rationale has continued into the post-1992 period, when the Australian government allowed entry into the provision of local and toll telephone calls. Further, research on subsequent data is required to answer this question.

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