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# The Cost Structure of Australian Telecommunications*

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*Since 1991 Australian telecommunications has undergone substantial reform. To a large extent, the economic correctness of pro-competitive policy depends on the non-existence of natural monopoly technology. This paper provides estimates of the Australian telecommunications system cost structure, and tests for subadditivity from 1943 to 1991. Additivity of the cost function after 1945 rejects the natural monopoly hypothesis and supports recent government policy. Diminished natural monopoly characteristics suggest that co-ordination between firms through networking can achieve similar economies as internal co-ordination within a monopoly. This finding is important, given the trend towards network unbundling, and service provision through interconnection.*

## I Introduction

Since 1991, the Australian telecommunications system has undergone substantial reform. The former publicly owned monopoly Telstra, established through the 1990 merger of Telecom and OTC, has been corporatized and partly privatized.[1] Competition in long-distance, international and mobile markets was fostered through the introduction of a private competitor Optus in 1991, with unrestricted market entry allowed after 1997. Administrative safeguards concerning network access and interconnection for new entrants were intended to reduce the risk of anti-competitive behaviour by the vertically integrated incumbent. To a large extent, the economic correctness of the above policy choices critically depends on whether Australian telecommunications exhibited natural monopoly

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[1] The Government sold a third of the public shareholding in Telstra through a public float in 1997, and a further 16 per cent in 1999.

characteristics.[2] Quiggin (1998, 1999) suggests that recent Australian telecommunications policy fails to adequately account for natural monopoly. He argues that alternative institutional structures, designed to exploit economies of scale and scope, may have provided lower industry costs. In particular, he calls for the restoration of full government ownership of Telstra, which would act as a common carrier system for cable TV and local telephony.[3] This would allow consumer access to all content providers regardless of the carrier supplying their access to the cable network.

Several potential sources of natural monopoly are possible in local telecommunications markets. Traditionally, returns to scale in local services arise from economies in the physical provision of basic services and in managerial economics of size, such as network planning, co-ordination and management.[4] Economies of scale can also arise as local networks are characterized by large network and call externalities that lead to a larger increase in traffic volume than in the number of subscribers (Sung and Gort 1997). Further, there are economies of sole provision due to cost savings accruing to integrated planning of network growth and switching capacity (Heenan 1989).[5] However, what is a natural monopoly is likely to change with technology and shifts in demand. For instance, while technology change may allow competition in previously monopolistic industries, it may also generate new sources of natural monopoly (Maddock 1999). Toward this end, it is unclear whether local telephone services currently involve a natural monopoly technology.

As noted by King (1997), the existence of a natural monopoly technology in Australian telecommunications is ultimately an empirical question. The cost structure of the telecommunications system can be estimated to infer the natural monopoly status of the industry. Unfortunately, the received econometric evidence of the presence of natural monopoly in telecommunications is largely unhelpful (Table 1). For instance, Evans and Heckman (1984, 1986) reject the hypothesis that the United States (US) Bell system was a natural monopoly during the pre-divestiture period, while Röller (1990a, 1990b), Diewert and Wales (1991a, 1991b), Pulley and Braunstein (1992) and Braunstein and Pulley (1998) find the system a natural monopoly. Braunstein and Pulley conclude that findings concerning the natural monopoly hypothesis for the Bell System are 'fragile'. In particular, they suggest that careful attention be given to the functional form of the cost function, and the properness of the estimated cost surface in both the estimating and forecast output regions.[6] Further, all of the above studies are based on the Christensen *et al.* (1983) data set that contains 31 annual time-series observations for the Bell system. Evans and Heckman (1988) conclude that finding better data, and not alternative estimation metrics, would be a more fruitful line of inquiry. The need to analyse Australian telecommunications systems cost data is even more necessary given the distinctly different institutional arrangements that has governed Australian and US industry evolution.

This paper provides the first publicly available estimates of the Australian telecommunications system cost structure. Estimation is on a unique data set constructed from Australia Post, Postmaster-General's (PMG) Department and Telecom Australia annual reports from 1926 to 1991. Tests of the system's cost structure for the presence of natural monopoly characteristics are

[2] The Hilmer committee recognized that when a final good or service is most efficiently produced by a natural monopoly technology then their competitive supply is socially wasteful (King 1997). An industry is a natural monopoly when its cost function $C(\mathbf{q}_i)$ is subadditive. That is, $C(\Sigma_i \mathbf{q}_i) \leq \Sigma_i C(\mathbf{q}_i)$ for all output vectors $\mathbf{q}_i$ (Baumol 1977; Baumol and Braunstein 1977).

[3] Common carriers offer telecommunications services to the public at large. Traditionally, common carriers have accepted universal service obligations for a high level of regulation that prevents them from facing open competition.

[4] Returns to scale in switching and transmission of signals enables service to be best provided within a local area through one or more switches, giving rise to a minimum efficient network size. The primary asset in a local network is the number of access lines, which are supported by switches and employees. A larger network may be able to handle randomly varying demand more efficiently by reallocations of capacity among switching and transmission equipment (Greenwald and Sharkey 1989).

[5] Potential economies of scope can arise from service to multiple local markets, joint provision of local and long-distance services, and joint provision of telephone, data and pay-TV services (Quiggin 1998).

[6] A proper cost function is non-negative and linear homogeneous, concave in input prices, and has positive marginal cost schedules.

TABLE 1
*Received Economic Evidence*

| Study | Firm | Period | Function | Outputs | Properness checked | Subadditivity |
|---|---|---|---|---|---|---|
| Bernstein (1988) | Bell Canada | 1954–1978 | Generalized Translog | Local, Toll | Not Reported | Not Reported |
| Bernstein (1989) | Bell Canada | 1954–1978 | Dynamic Translog | Local, Toll | Not Reported | Not Reported |
| Braunstein and Pulley (1998) | Bell system | 1947–1977 | Composite | Local, Toll | Yes | Global: Yes |
| Charnes *et al.* (1988) | Bell system | 1947–1977 | Translog | Local, Toll | Not Applicable | Local: Yes |
| Diewert and Wales (1991a) | Bell system | 1947–1977 | Normalized Translog | Local, Toll | Yes | Local: Yes |
| Evans and Heckman (1983, 1984, 1986, 1988) | Bell system | 1947–1977 | Translog | Local, Toll | No | Local: No |
| Foreman and Beauvais (1999) | 101 GTE Cellular Market Areas | 1996–1998 | Translog | Cellular | Not Reported | Not Applicable |
| Guldmann (1990) | Forty-Four US LECs | 1980 | Translog | Local, Toll | No | Not Applicable |
| Lopez (1997) | Telefonica (Spain) | 1974–1994 | Generalized Translog | Local, Toll | Yes | Not Applicable |
| McKenzie and Small (1997) | Five Cellular Firms | 1993–1995 | Composite | Cellular | Yes | Not Reported |
| Pulley and Braunstein (1992) | Bell system | 1947–1977 | Composite | Local, Toll | Yes | Expanded local: Yes |
| Röller (1990a) | Bell system | 1947–1979 | CES-Quadratic | Local, Toll | Yes | Global: Yes |
| Serifica (1998) | PLDT (Philippine Telecom) | 1951–1993 | Translog | Local, Toll | No | Local: Yes |
| Shin and Ying (1992) | Fifty-Eight US LECs | 1976–1983 | Translog | Local, Toll | Yes | Global: No |
| Sung and Gort (1997) | Eight US LECs | 1951–1991 | Translog | Local, Toll | Yes | Local: Yes |

*Note:* LECs are local exchange carriers.

also undertaken. A test for natural monopoly for Australian telecommunications may seem unnecessary at this point, with the sector open to competition. Nevertheless, the presence of economies of scope may prove important for issues facing an emerging information economy. For instance, whether the recent spate of mergers to form global communications companies, and so allow the delivery of service bundles, is in the Australian public interest. Evidence presented here might provide some indication as to the extent of cost efficiencies achieved from convergence of broadcasting and telecommunications operators. The presence of natural monopoly characteristics also presupposes that market co-ordination between separate firms (by networking or interconnection) is less able to achieve the same economies as internal co-ordination within a firm. With increasing unbundling and interconnection of telecommunications services, it is not clear that this presumption holds (Albon *et al.* 1997).

The paper is organized as follows. A selective history of the Australian telecommunications system is given in section II, and telecommunications performance from 1950 to 1991 is described in section III. Section IV discusses the merits and appropriateness of applying the translog cost function, and describes the data used for estimation. The introduction of a quadratic spline function to model technological change is described in section V and its integration into the cost function in section VI. An empirically tractable test for local subadditivity is described and implemented in section VII. Concluding remarks and policy implications are provided in section VIII.

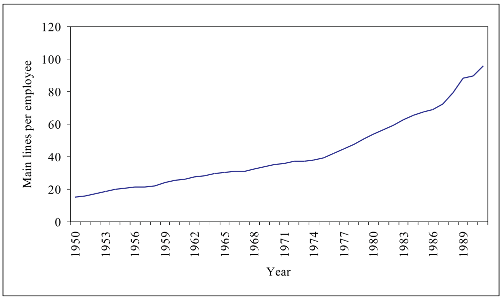
## *II The Australian Telecommunications System*

The Constitution Act 1900 authorized the Commonwealth government to take over and administer the postal and telegraph departments of each State of the newly formed Commonwealth. On 1 March 1901, the separate Colonial departments were amalgamated into the PMG Department of the Commonwealth. The PMG was solely responsible for telecommunications service provision and regulation until the Overseas Telecommunications Act 1946 established OTC to provide international facilities and services. The Telecommunications Act 1975 separated post and telecommunications service provision, and established Telecom as the provider of local and long-distance telephone services. In 1981, AUSSAT was created to develop a national satellite system, while AUSTEL was established as the independent regulator in 1989. The Telecommunications Act 1991 introduced competition into the market place. Telecom and OTC merged into a single general carrier, Telstra, while Optus Communications purchased AUSSAT to create a second general carrier. The Commonwealth government assured Optus that no new general carrier licences would be granted prior to July 1997. The Optus licence required the company to supply long-distance and international services to the entire Australian population by December 1997 (Bureau of Transport and Communications Economics 1995). Post-1997 arrangements require that general carriers interconnect any other carrier or service provider on request, so long as sufficient capacity is available and the specified interconnection is technically feasible. On 1 July 1997, regulatory responsibility was passed from AUSTEL to the Australian Competition and Consumer Commission.

## *III Telecommunications Performance*

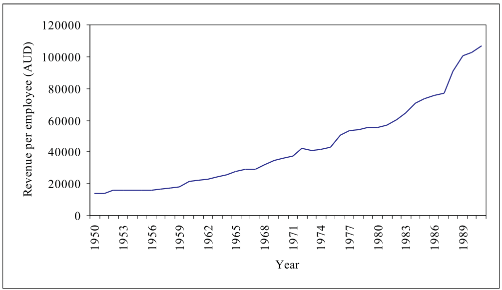
Australian telecommunications performance is described by various productivity, cost and output measures.[7] Partial productivity measures are presented in Figures 1–3. The ratio of telephone mainlines to full-time employees (MPE) provides an indication of labour productivity relating to the construction, maintenance and operation of the network. The rapid increase in MPE, 4.6 per

FIGURE 1
*Mainlines per Employee 1950–91*




*Source.* Communication Economics and Electronic Markets Research Centre (CEEM; 2001).

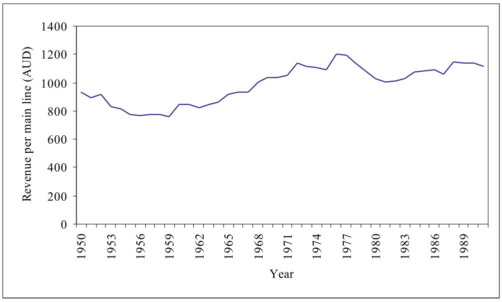
FIGURE 2
*Revenue per Employee 1950–91*




*Source.* CEEM 2001.

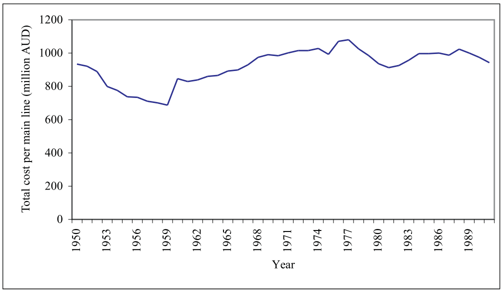
[7] Revenue and costs are deflated by the CPI (1990 = 100).

FIGURE 3
*Revenue per Mainline 1950–91*




*Source.* CEEM 2001.

FIGURE 5
*Total Cost per Telephone Exchange 1950–87*

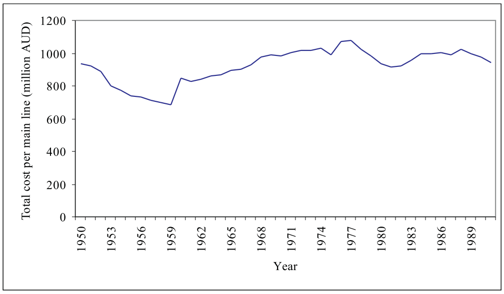



*Source.* CEEM 2001.

cent per annum (p.a.) from 1950 to 1991, largely reflects capital for labour substitution. Labour's share of telecommunications total costs declined from 78 per cent in 1950 to 34 per cent in 1991. Another indicator of labour productivity is the ratio of telecommunications service revenue to full-time employees (RPE). RPE has also experienced substantial growth during the post-war period (5.1 per cent p.a.) and reflects, in part, labour-shedding effects. The ratio of telecommunications service revenue to mainlines (RPL) measures capital productivity. RPL provides a guide to the intensity of network usage and is important to investment planners as it provides an indication of the required payback period. RPL declined from 1950 to 1959, and then experienced steady growth until the mid-1970s. A substantial fall in RPE in the mid-1970s coincides with the break up of the PMG into Australia Post and Telecom.

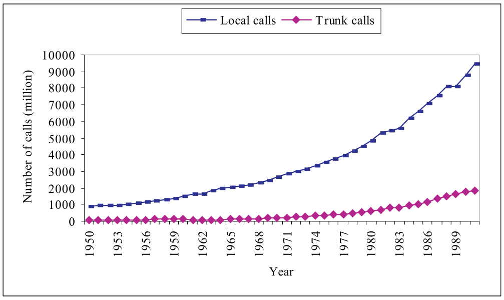
Figures 4 and 5 show total cost per mainline and exchange (offices with one or more subscriber lines connected), respectively. Total cost per mainline is stable during the post-war period which suggests costs have grown commensurately with mainlines. Cost per exchange increased 6.2 per cent p.a. from $110,471 in 1950 to $1,305,573 in 1991. This reflects a reduction in exchanges as new technology has allowed the geographical coverage of local service areas to be extended. For instance, the proportion of telephone lines connected to automatic exchanges increased from about 61 per cent in 1950 to approximately 99 per cent in 1980. Finally, data on telecommunications outputs are presented in Figure 6. Local calls increased 6 per cent p.a. from 1950 to 1991. Facilities for subscriber dialled trunk calls were introduced in the mid-1960s. Between 1970 and 1991, toll (long-distance) calls grew at a rate of 11.2 per cent p.a., compared to 6.2 per cent p.a. for local calls.

FIGURE 4
*Total Cost per Mainline 1950–91*




*Source.* CEEM 2001.

FIGURE 6
*Number of Telephone Calls 1950–91*




*Source.* CEEM 2001.

## IV Cost Function Estimation

Telecommunications technology can be studied empirically using a variety of methods such as cost, distance, labour-requirements, production, profit or transformation function approaches. The cost function approach defines the firm's minimum cost of providing a set of telecommunications services, conditional on given purchase prices of the factors of production and on a particular state of technology. Cost function specification implies the output level is exogenous. Australian telecommunications services were provided by a public monopoly until 1991. The monopoly was not allowed to choose its own production level to maximize profits, but required to supply all services demanded at regulated prices, subject to meeting universal service obligations. Since decisions were made with regard to the determination of the optimal levels of inputs, the specification that input levels are endogenous and output is exogenous is a reasonable assumption.

Australian telecommunications can be described by the multi-product translog cost function. The key advantage of the translog is that it avoids imposing *a priori* restrictions on substitution elasticities. Further flexibility is incorporated into the cost model by adding a spline function that allows for non-constant exogenous technical change.[8]

## V Quadratic Spline Function

Quadratic spline functions provide an efficient method of allowing model parameters to vary across sub-samples of the data while maintaining continuity at the joins. Radical changes in technology over the sample period require a function capable of permitting the effects of technology to change from one era to another. Specification of a flexible technological progress function is provided by

$$\begin{aligned}\text{Tech} = {} & [a_0 + b_0(t - t_0) + c_0(t - t_0)^2] \cdot d_0 \\ & + [a_1 + b_1(t - t_1) + c_1(t - t_1)^2] \cdot d_1 \\ & + \sum_{i=2}^{n} [a_i + b_i(t - t_i) + c_i(t - t_i)^2] \cdot d_i \quad (1)\end{aligned}$$

where $t$ is a time trend, $t_i$ are specific fixed periods (or knots), the dummy variable $d_0 = 1$ when $t_0 < t \leq t_1$ and zero otherwise, $d_1 = 1$ when $t_1 < t \leq t_2$ and zero otherwise, $d_2 = 1$ when $t_2 < t \leq t_3$ and zero otherwise, and the $a_i$, $b_i$ and $c_i$ are parameters to be estimated.

To ensure the technology function meets at the knots and is continuous to at least the first derivative, it is necessary to constrain (1). Following Suits *et al.* (1978), the Tech function is specified as

$$\begin{aligned}\text{Tech} = {} & a_0 + b_0(t - t_0) + c_0(t - t_0)^2 + (c_1 - c_0) \\ & \times (t - t_1)^2 D_1 + (c_2 - c_1)(t - t_2)^2 D_2 \\ & + \sum_{i=3}^{n} (c_i - c_{i-1})(t - t_i)^2 D_i \quad (2)\end{aligned}$$

where the $D_i$ are defined as: $D_1 = 1$, if $t_1 < t$ and zero otherwise, and $D_2 = 1$, if $t_2 < t$ and zero otherwise.

Setting $t_0 = 0$, (2) becomes

$$\begin{aligned}\text{Tech} = {} & a_0 + b_0 t + c_0 t^2 + (c_1 - c_0) \\ & \times (t - t_1)^2 \cdot D_1 + (c_2 - c_1)(t - t_2)^2 \cdot D_2 \\ & + \sum_{i=3}^{n} (c_i - c_{i-1})(t - t_i)^2 \cdot D_i \quad (3)\end{aligned}$$

## VI Cost Function Restrictions

To ensure a proper cost function is estimated, symmetry and homogeneity restrictions are imposed. Symmetry restrictions imply that $\gamma_{LT} = \gamma_{TL}$ and $\delta_{LK} = \delta_{KL}$. Homogeneity restrictions imply that $\beta_L + \beta_K = 1$, $\delta_{LL} + \delta_{LK} = 0$, $\delta_{KL} + \delta_{KK} = 0$, $\rho_{LL} + \rho_{LK} = 0$, $\rho_{TL} + \rho_{TK} = 0$, $\phi_{wL1} + \phi_{wK1} = 0$, $\phi_{wL2} + \phi_{wK2} = 0$ and $\lambda_L + \lambda_K = 0$. Imposing these restrictions on the translog cost function with quadratic spline arguments allowing for four intervals results in the estimating equation:

$$\begin{aligned}\ln\left(\frac{C}{w_K}\right) = {} & \alpha_0 + \alpha_L \ln q_L + \alpha_T \ln q_T \\ & + \beta_L \ln\left(\frac{w_L}{w_K}\right) + \mu t + \gamma_{LT} \ln q_L \ln q_T \\ & + \rho_{LL} \ln q_L \ln\left(\frac{w_L}{w_K}\right) + \rho_{TL} \ln q_T \ln\left(\frac{w_L}{w_K}\right)\end{aligned}$$

[8] The translog is often criticized for not being robust at close to zero output levels. Röller (1990b) uses a generalized CES-quadratic cost function that can model cost behaviour in the range of zero outputs. Pulley and Braunstein (1992) propose the composite cost function, which combines the log-quadratic input price structure of the translog with a quadratic structure for multiple outputs. The composite cost function improves on the CES-quadratic form by not imposing separability. Here, the translog is used with greater attention paid to the properness of the estimated cost surface.

$$
\begin{aligned}
&+\lambda_{\mathrm{L}}\ln q_{\mathrm{L}}\cdot t+\phi_{\mathrm{L0}}\ln q_{\mathrm{L}}\cdot t^2+\phi_{\mathrm{L1}}\ln q_{\mathrm{L}}\\
&\times(t-t_1)^2\cdot D_1+\phi_{\mathrm{L2}}\ln q_{\mathrm{L}}(t-t_2)^2\cdot D_2\\
&+\phi_{\mathrm{L3}}\ln q_{\mathrm{L}}(t-t_3)^2\cdot D_3+\lambda_{\mathrm{T}}\ln q_{\mathrm{T}}\cdot t\\
&+\phi_{\mathrm{T0}}\ln q_{\mathrm{T}}\cdot t^2+\phi_{\mathrm{T1}}\ln q_{\mathrm{T}}(t-t_1)^2\cdot D_1\\
&+\phi_{\mathrm{T2}}\ln q_{\mathrm{T}}(t-t_2)^2\cdot D_2\\
&+\phi_{\mathrm{T3}}\ln q_{\mathrm{T}}(t-t_3)^2\cdot D_3+\lambda_{\mathrm{wL}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\cdot t\\
&+\phi_{\mathrm{wL0}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\cdot t^2+\phi_{\mathrm{wL1}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\\
&\times(t-t_1)^2\cdot D_1+\phi_{\mathrm{wL2}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\\
&\times(t-t_2)^2\cdot D_2+\phi_{\mathrm{wL3}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\\
&\times(t-t_3)^2\cdot D_3+\gamma_{\mathrm{LL}}\tfrac{1}{2}(\ln q_{\mathrm{L}})^2\\
&+\gamma_{\mathrm{TT}}\tfrac{1}{2}(\ln q_{\mathrm{T}})^2+\delta_{\mathrm{LK}}\tfrac{1}{2}\left(\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\right)^2\\
&+\gamma_{\mathrm{tt}}\tfrac{1}{2}t^2+\phi_{\mathrm{t1}}\tfrac{1}{2}(t-t_1)^2\cdot D_1\\
&+\phi_{\mathrm{t2}}\tfrac{1}{2}(t-t_2)^2\cdot D_2+\phi_{\mathrm{t3}}\tfrac{1}{2}(t-t_3)^2\cdot D_3 \qquad (4)
\end{aligned}
$$

where ln is the natural logarithm operator, $C$ is the total cost of producing telephone services, $q_{\mathrm{L}}$ is the number of local calls, $q_{\mathrm{T}}$ is the number of toll calls, $w_{\mathrm{L}}$ (labour price) is total salary expense divided by the number of employees, $w_{\mathrm{K}}$ (capital price) is calculated from residual expenses (total cost less labour expenses), divided by mainlines. All data are obtained from CEEM (2001).

By Shephard's Lemma $x_i = \partial c/\partial w_i$, where $x_i$ is the quantity demanded for the $i$th factor. The corresponding cost share equation for labour is

$$
\begin{aligned}
S_{\mathrm{L}}=\frac{\partial\ln C}{\partial\ln w_{\mathrm{L}}}&=\beta_{\mathrm{L}}+\delta_{\mathrm{LK}}\ln\left(\frac{w_{\mathrm{L}}}{w_{\mathrm{K}}}\right)\\
&+\rho_{\mathrm{LL}}\ln q_{\mathrm{L}}+\rho_{\mathrm{TL}}\ln q_{\mathrm{T}}+\lambda_{\mathrm{wL}}t+\phi_{\mathrm{wL0}}t^2\\
&+\phi_{\mathrm{wL1}}(t-t_1)^2\cdot D_1+\phi_{\mathrm{wL2}}(t-t_2)^2\cdot D_2\\
&+\phi_{\mathrm{wL3}}(t-t_3)^2\cdot D_3 \qquad (5)
\end{aligned}
$$

Summary statistics for all variables are provided in Table 2.

The translog cost function (4) and labour share equation (5) are estimated by Zellner's (1962) seemingly unrelated regression estimation (SURE) technique using annual data from 1926 to 1991. Model estimation allows for first-order autocorrelation in each equation. Restricted SURE results for (1) are presented in Table 3.

Twelve of the 18 estimated coefficients are significant at the 10% level. All first-order terms, except for toll output, are significant while the second-order output coefficients are of plausible magnitudes. These latter estimates contrast with those of Evans and Heckman (1984), Bloch *et al.* (1998), Charnes *et al.* (1988) and Serafica (1998) which have absolute values in the range of four to ten. Large second-order output elasticities imply that a per cent increase in output causes an implausibly large change in the output cost elasticity, and suggests inferences regarding economies of scale and scope must be fragile (Braunstein and Pulley 1998). For labour input price, the cost elasticity or factor share coefficient (Labour) is positive and has plausible magnitude.

TABLE 2
*Summary Statistics*

| | | Mean | Std dev. | Max | Min |
|---|---|---|---|---|---|
| Cost ($m) | C | 1100 | 2017 | 7906 | 13 |
| Local calls (m) | $q_{\mathrm{L}}$ | 2448 | 2437 | 9446 | 300 |
| Toll calls (m) | $q_{\mathrm{T}}$ | 311 | 462 | 1832 | 23 |
| Labour price ($) | $w_{\mathrm{L}}$ | 5991 | 8737 | 32163 | 384 |
| Capital price ($) | $w_{\mathrm{K}}$ | 105 | 169 | 647 | 6.60 |
| Capital share | $S_{\mathrm{K}}$ | 0.34 | 0.13 | 0.66 | 0.16 |
| Labour share | $S_{\mathrm{L}}$ | 0.66 | 0.13 | 0.84 | 0.34 |

TABLE 3
*Restricted Sure Estimation Results For* (4)

| Variable | Parameter | *t*-ratio |
|---|---|---|
| Constant | −2.009 | −0.518 |
| Local | 0.994 | 2.144 |
| Toll | −1.625 | −0.661 |
| Local × Local | −0.009 | −0.178 |
| Toll × Toll | 1.258 | 1.391 |
| Local × Toll | −0.319 | −2.108 |
| Technology × Local | 0.010 | 1.503 |
| Technology × Toll | −0.092 | −1.750 |
| Technology | 0.490 | 3.147 |
| Technology × Technology | −0.019 | −1.471 |
| Local × Labour price | −0.031 | −4.068 |
| Toll × Labour price | −0.037 | −2.204 |
| Labour price | 0.436 | 4.235 |
| Labour price × Labour price | 0.086 | 2.589 |
| Technology × Labour price | 0.004 | 3.321 |
| Spline 1 (1928) | 0.013 | 2.128 |
| Spline 2 (1968) | 0.008 | 1.202 |
| Spline 3 (1978) | −1.537 | −1.726 |
| | Cost function | Labour share |
| Adjusted $R^2$ | 0.99 | 0.43 |
| Autocorrelation | −0.01 | −0.01 |

The time placement of knots is *a priori* difficult as the impact of technical progress on costs is not directly observable. Following Diewert and Wales (1992), a grid search determines the location of the three knots (Spline 1, Spline 2 and Spline 3) of the quadratic spline according to the maximum of the likelihood function. To derive estimates consistent with theory, all spline interaction parameters are set to zero. The splines allow for shifts in technology by modifying the time trend. As indicated in Table 3, Spline 1 corresponds to 1928, Spline 2 to 1968 and Spline 3 to 1978. Spline 1 is located very close to the beginning of the sample data and, by its location, suggests a substantial change in technology between the 1926–28 period relative to the 1928–68 interval. Moreover, Spline 1 and Spline 2 are located close to data points corresponding to shifts in toll output in periods 1931 and 1960. The former point coincides with the Great Depression while the latter accords with the introduction of extended local service areas (PMG 1960).[9]

Table 4 presents summary statistics for the estimated translog cost function. Own price elasticity estimates of demand for labour (EPL) and capital (EPK) are inelastic for the entire sample. TECH, the per cent change in cost due to changing technology, is negative when technology is cost saving. TECH is found always positive and large in magnitude, although the estimates decline through time. Elasticity estimates of cost for local (EQ1) and toll (EQ2) output are unit elastic and inelastic, respectively.[10] Returns to scale (RS) show constant returns to scale until the post-war period, and then trend upward, revealing scale economies by the 1980s.

## *VII Properness and Subadditivity*

When cost function estimation is undertaken with a view to testing for natural monopoly, global information about the cost function is required. To overcome data limitations, Evans and Heckman (1983, 1984) propose a local test of natural monopoly that does not require global information on firms' cost functions by restricting the test to the admissible region. The admissible region is the area where no firm produces less of either output than is observed in market data, and the hypothetical firms produce in the range of ratios of outputs actually observed in these data. This restriction avoids making inferences outside the observed output combinations, while the test area is restricted to the region where the estimates are most likely to be well behaved (the centre of the observations). Their test rejects global subadditivity when subadditivity is rejected in a region, while acceptance of local subadditivity does not imply global subadditivity.

Formally, the cost function $C(q_L, q_T)$, is subadditive at $(q_L, q_T)$ if and only if

$$C(q_L, q_T) = C[\phi q_L + (1-\phi)q_L, \omega q_T + (1-\omega)q_T] \leq C(\phi q_L, \omega q_T) + C[(1-\phi)q_L, (1-\omega)q_T] \quad (6)$$

for all $0 \leq \phi, \omega \leq 1$.

For firms A and B, and outputs $q_L$ and $q_T$, the degree of subadditivity associated with alternative output allocations $(\phi, \omega)$ are defined as

$$\text{Sub}(\phi, \omega) = \frac{C_T - C_A(\phi, \omega) - C_B(\phi, \omega)}{C_T} \quad (7)$$

where $C_A(\phi, \omega)$ and $C_B(\phi, \omega)$ are the costs to firm A and firm B of producing the output combinations $(q_{LA}, q_{TA})$ and $(q_{LB}, q_{TB})$, respectively, and $C_T$ is the cost of single firm production. The production levels for A and B of the two goods are determined by

$$\begin{aligned} q_{LA} &= \phi(q_{LA} - 2q_{LM}) + q_{LM} \\ q_{TA} &= \omega(q_{TA} - 2q_{TM}) + q_{TM} \end{aligned} \quad (8)$$

where $0 \leq \phi$, $\omega \leq 1$, and $q_{LM}$ and $q_{TM}$ are the minimum levels of local and toll output observed in the sample. When $\text{Sub}(\phi, \omega) > 0 (< 0)$, the monopoly situation is less (more) efficient than the two-firm allocation described by that $(\phi, \omega)$ combination. The value of $\text{Sub}(\phi, \omega)$ represents the per cent gain or loss from two firm production versus single firm production. In calculating the $\text{Sub}(\phi, \omega)$ in (7), the fitted cost function from (4) for each year is used. Total observed output is divided between the hypothetical firms and total cost for each firm is calculated using the estimated cost function (4) with the theoretical outputs rather than the observed total output.

As none of Evans and Heckman's hypothetical output combinations satisfy the conditions of a proper cost function, their subadditivity tests are

[9] The PMG Annual Report for 1960 reported a 40 per cent diversion of traffic from toll to local calls through the extension of local call areas.

[10] Negative EQ2 implies negative marginal costs of toll output. This finding is not unique to this study with Diewert and Wales (1991a) reporting negative values of $\partial C/\partial q_2$ for 21 of their 31 observations.

TABLE 4
*Summary Statistics for Translog Cost Function*

| Years | EPL | EPK | TECH | EQ1 | EQ2 | RS |
|---|---|---|---|---|---|---|
| 1926 | −0.0479 | −0.0321 | 0.4602 | 1.0722 | −0.0186 | 0.9491 |
| 1927 | −0.0476 | −0.0324 | 0.4586 | 1.0662 | −0.0223 | 0.9579 |
| 1928 | −0.0418 | −0.0382 | 0.4570 | 1.0610 | −0.0224 | 0.9628 |
| 1929 | −0.0408 | −0.0392 | 0.4555 | 1.0543 | −0.0242 | 0.9707 |
| 1930 | −0.0402 | −0.0398 | 0.4535 | 1.0517 | −0.0255 | 0.9745 |
| 1931 | −0.0448 | −0.0352 | 0.4543 | 1.0278 | −0.0241 | 0.9963 |
| 1932 | −0.0327 | −0.0473 | 0.4532 | 1.0187 | −0.0238 | 1.0051 |
| 1933 | −0.0329 | −0.0471 | 0.4507 | 1.0200 | −0.0245 | 1.0045 |
| 1934 | −0.0327 | −0.0473 | 0.4475 | 1.0259 | −0.0286 | 1.0027 |
| 1935 | −0.0296 | −0.0504 | 0.4441 | 1.0337 | −0.0297 | 0.9961 |
| 1936 | −0.0293 | −0.0507 | 0.4404 | 1.0438 | −0.0379 | 0.9942 |
| 1937 | −0.0285 | −0.0515 | 0.4380 | 1.0442 | −0.0412 | 0.9970 |
| 1938 | −0.0287 | −0.0513 | 0.4347 | 1.0516 | −0.0426 | 0.9912 |
| 1939 | −0.0295 | −0.0505 | 0.4321 | 1.0528 | −0.0478 | 0.9949 |
| 1940 | −0.0291 | −0.0509 | 0.4302 | 1.0499 | −0.0527 | 1.0028 |
| 1941 | −0.0291 | −0.0509 | 0.4281 | 1.0476 | −0.0551 | 1.0075 |
| 1942 | −0.0292 | −0.0508 | 0.4267 | 1.0404 | −0.0613 | 1.0214 |
| 1943 | −0.0306 | −0.0494 | 0.4249 | 1.0368 | −0.0733 | 1.0379 |
| 1944 | −0.0306 | −0.0494 | 0.4227 | 1.0352 | −0.0729 | 1.0392 |
| 1945 | −0.0314 | −0.0486 | 0.4196 | 1.0412 | −0.0705 | 1.0302 |
| 1946 | −0.0326 | −0.0474 | 0.4164 | 1.0472 | −0.0684 | 1.0217 |
| 1947 | −0.0297 | −0.0503 | 0.4134 | 1.0517 | −0.0689 | 1.0174 |
| 1948 | −0.0303 | −0.0497 | 0.4107 | 1.0545 | −0.0716 | 1.0174 |
| 1949 | −0.0314 | −0.0486 | 0.4072 | 1.0629 | −0.0743 | 1.0115 |
| 1950 | −0.0286 | −0.0514 | 0.4044 | 1.0665 | −0.0720 | 1.0055 |
| 1951 | −0.0317 | −0.0483 | 0.4017 | 1.0689 | −0.0809 | 1.0122 |
| 1952 | −0.0298 | −0.0502 | 0.3994 | 1.0690 | −0.0863 | 1.0177 |
| 1953 | −0.0296 | −0.0504 | 0.3982 | 1.0603 | −0.0819 | 1.0220 |
| 1954 | −0.0295 | −0.0505 | 0.3955 | 1.0625 | −0.0834 | 1.0214 |
| 1955 | −0.0445 | −0.0355 | 0.3933 | 1.0613 | −0.0857 | 1.0250 |
| 1956 | −0.0443 | −0.0357 | 0.3912 | 1.0592 | −0.0881 | 1.0297 |
| 1957 | −0.0437 | −0.0363 | 0.3886 | 1.0615 | −0.0921 | 1.0316 |
| 1958 | −0.0432 | −0.0368 | 0.3862 | 1.0613 | −0.0932 | 1.0329 |
| 1959 | −0.0407 | −0.0393 | 0.3839 | 1.0612 | −0.0972 | 1.0373 |
| 1960 | −0.0444 | −0.0356 | 0.3814 | 1.0623 | −0.1001 | 1.0393 |
| 1961 | −0.0457 | −0.0343 | 0.3791 | 1.0618 | −0.1015 | 1.0413 |
| 1962 | −0.0446 | −0.0354 | 0.3767 | 1.0625 | −0.1048 | 1.0442 |
| 1963 | −0.0424 | −0.0376 | 0.3743 | 1.0626 | −0.1084 | 1.0480 |
| 1964 | −0.0415 | −0.0385 | 0.3719 | 1.0627 | −0.1121 | 1.0520 |
| 1965 | −0.0402 | −0.0398 | 0.3693 | 1.0649 | −0.1100 | 1.0472 |
| 1966 | −0.0383 | −0.0417 | 0.3667 | 1.0664 | −0.1143 | 1.0503 |
| 1967 | −0.0387 | −0.0413 | 0.3642 | 1.0680 | −0.1179 | 1.0525 |
| 1968 | −0.0360 | −0.0440 | 0.3616 | 1.0692 | −0.1191 | 1.0525 |
| 1969 | −0.0584 | −0.0216 | 0.3591 | 1.0701 | −0.1209 | 1.0534 |
| 1970 | −0.0608 | −0.0192 | 0.3567 | 1.0711 | −0.1250 | 1.0569 |
| 1971 | −0.0598 | −0.0202 | 0.3546 | 1.0687 | −0.1257 | 1.0604 |
| 1972 | −0.0622 | −0.0178 | 0.3522 | 1.0690 | −0.1283 | 1.0630 |
| 1973 | −0.0637 | −0.0163 | 0.3499 | 1.0690 | −0.1327 | 1.0680 |
| 1974 | −0.0629 | −0.0171 | 0.3474 | 1.0697 | −0.1371 | 1.0723 |
| 1975 | −0.0666 | −0.0134 | 0.3452 | 1.0686 | −0.1420 | 1.0792 |
| 1976 | −0.0619 | −0.0181 | 0.3432 | 1.0659 | −0.1442 | 1.0849 |
| 1977 | −0.0575 | −0.0225 | 0.3410 | 1.0647 | −0.1458 | 1.0882 |
| 1978 | −0.0576 | −0.0224 | 0.3389 | 1.0632 | −0.1499 | 1.0949 |
| 1979 | −0.0551 | −0.0249 | 0.3371 | 1.0591 | −0.1532 | 1.1039 |
| 1980 | −0.0552 | −0.0248 | 0.3350 | 1.0566 | −0.1563 | 1.1107 |

TABLE 4 (*continued*)

| Years | EPL | EPK | TECH | EQ1 | EQ2 | RS |
|---|---|---|---|---|---|---|
| 1981 | −0.0540 | −0.0260 | 0.3321 | 1.0611 | −0.1584 | 1.1078 |
| 1982 | −0.0538 | −0.0262 | 0.3301 | 1.0583 | −0.1620 | 1.1157 |
| 1983 | −0.0515 | −0.0285 | 0.3274 | 1.0611 | −0.1658 | 1.1170 |
| 1984 | −0.0480 | −0.0320 | 0.3258 | 1.0553 | −0.1701 | 1.1296 |
| 1985 | −0.0461 | −0.0339 | 0.3235 | 1.0549 | −0.1731 | 1.1341 |
| 1986 | −0.0429 | −0.0371 | 0.3207 | 1.0577 | −0.1751 | 1.1330 |
| 1987 | −0.0402 | −0.0398 | 0.3181 | 1.0597 | −0.1770 | 1.1329 |
| 1988 | −0.0363 | −0.0437 | 0.3165 | 1.0542 | −0.1827 | 1.1474 |

*Note:* TECH $= \frac{\partial \ln C}{\partial t}$, RS $= \left(\sum \frac{\partial \ln C}{\partial \ln q_i}\right)^{-1}$, $i =$ L, T.

unlikely to be reliable (Röller 1990a; Diewert and Wales 1991a; Salvanes and Tjøtta 1998). To avoid this problem, Salvanes and Tjøtta suggest testing for subadditivity over the consistency region where the cost function is proper.[11] Prior to conducting subadditivity tests, the regularity conditions for a proper cost function are considered. Linear homogeneity in input prices and symmetry are imposed *a priori* during estimation, while continuity follows from the functional form. The marginal cost with respect to outputs are non-negative when[12]

$$\frac{\partial \ln C}{\partial \ln q_i} = \alpha_i + \gamma_{ij} \ln q_j + \lambda_i t + \phi_{i0} q_i t^2 + \phi_{i1}(t - t_1)^2 \cdot D_1 + \sum_{k=2}^{n} \phi_{ik}(t - t_k)^2 \cdot D_k + \gamma_{ii} \ln q_i \geq 0 \tag{9}$$

Substitution of cost function estimates and sample observations into (9) reveals that none of the 66 observations have negative marginal costs with respect to local output. The final properness condition is that the cost function be concave in input prices. Following Diewert and Wales (1987), the cost function is concave in input prices since the matrix

$$\Gamma(q) \equiv \begin{bmatrix} \delta_{\mathrm{LL}} - S_{\mathrm{L}}^*(1 - S_{\mathrm{L}}^*) & \delta_{\mathrm{LK}} + S_{\mathrm{L}}^* S_{\mathrm{K}}^* \\ \delta_{\mathrm{KL}} + S_{\mathrm{K}}^* S_{\mathrm{L}}^* & \delta_{\mathrm{KK}} - S_{\mathrm{K}}^*(1 - S_{\mathrm{K}}^*) \end{bmatrix} \tag{10}$$

is negative definite (where $^*$ indicates the estimated cost shares). Finally, both local and toll service doubled by 1943, making it the first possible year for implementation of the subadditivity test. Between 1943 and 1991, the ratio of local to toll output lay between 4.88 and 21.67.

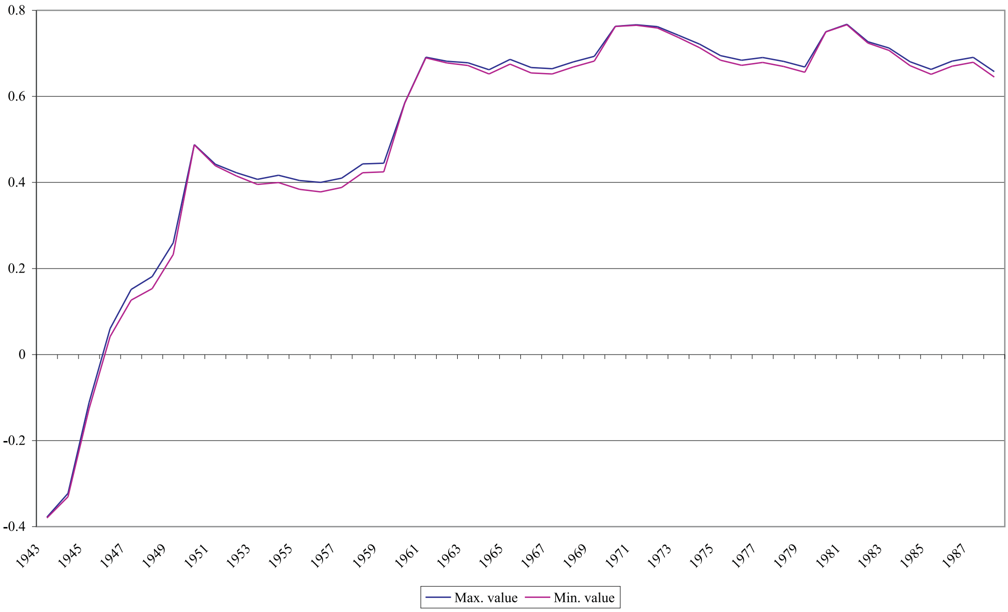
Sub$(\phi, \omega)$ is calculated for the combinations of $(\phi, \omega)$ corresponding to $\phi = 0, 0.1, 0.2, \ldots, 0.9, 1$ and $\omega = 0, 0.1, 0.2, \ldots, 0.9, 1$ for each year 1943 through 1991.[13] When $\phi$ is equal to zero, the firm produces only the observed minimum in local call output. When $\phi$ is equal to one, the firm has 100 per cent market share of the output in excess of twice the observed minimum local call output. Similarly, $\omega$ has the same interpretation for toll output. Figure 7 plots the maximum Sub$(\phi, \omega)$ from 1943 to 1988. An upward trend in Sub$(\phi, \omega)$ from negative to positive values suggests the evolution of cost additivity is associated with exogenous technology change. The maximum Sub$(\phi, \omega)$ is negative from 1943 to 1945. After 1945, the maximum Sub$(\phi, \omega)$ is positive, rejecting local subadditivity of the cost function. Of particular interest is the point of entry for Optus close to the introduction of competition. Firm A is set as a new entrant in the long-distance market competing with an incumbent monopolist, providing minimum local service, but capturing 50 per cent of the toll market (Sub(0, 0.5)). This configuration yields a subadditivity measure of 0.6517, showing that two firms provide telecom-

[11] When the consistency region is not empty, it is within this region that a productivity measure such as the degree of subadditivity makes sense. With the test region being the consistency region or the domain of the estimated cost function, the finding of natural monopoly locally is a necessary and sufficient condition for global natural monopoly.

[12] Note that (9) is the cost elasticity with respect to output. However, since the elasticity is defined as the ratio of marginal to average costs, positive marginal costs require positive elasticities.

[13] Firms are prevented from producing zero outputs where the translog cost function would not be defined.

FIGURE 7
*Maximum Gain (Loss) from Two-firm Production vs. Single-firm Production 1943–88*




munication services 65 per cent more efficiently than the government controlled monopoly. The hypothesis that the production of Australian local and toll services is a natural monopoly is rejected after 1945 since the cost of single firm production is higher than the cost of two firms producing the same level of services.

## *VIII Conclusions*

Since 1991, the Australian telecommunications system has been privatized and competition introduced. The economic correctness of the pro-competitive policy depends on the natural monopoly status of Australian telecommunications at the time policy was implemented. This paper provides the first publicly available estimates of the Australian telecommunications system cost structure. A test of the system's cost structure for natural monopoly characteristics is undertaken, with careful attention given to ensuring the subadditivity test is implemented over the proper region of the cost surface. Finally, we follow Evans and Heckman's (1988) dictum and find data of longer span, constructed from Australia Post, PMG and Telecom Australia annual reports for 1926–91.

The estimated cost function is statistically well specified, with all second-order output coefficients displaying plausible magnitudes. The subaddivity test is calculated for each year from 1943 through 1988. Additivity of the cost function after 1945 rejects the natural monopoly hypothesis and provides qualified support for recent government policy that has progressively introduced more competition into Australian telecommunications markets. Diminishing natural monopoly characteristics also suggests that market co-ordination between separate firms through networking is able to achieve similar economies as internal co-ordination with a monopoly. This finding is important given the trend towards unbundling telecommunications network elements, and the provision of telecommunications services through interconnection.

Finally, Röller (1990a, 1990b) and Pulley and Braunstein (1992) suggest that tests for natural monopoly are sensitive to the functional form of the cost function. Future research will employ a composite cost function to examine subadditivity in Australian telephone services. The composite cost model is useful because it also permits the measurement of economies of scale, economies of scope and subadditivity, without prejudging their presence. Finally, as market data become available, a test for subadditivity will be implemented for output combinations dictated by actual Optus and Telstra market shares.

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