Public Infrastructure, Regional Efficiency, and Factor Substitutability in Atlantic Canada Manufacturing

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Efficient infrastructure, in appropriate quantity, is critical to economic performance. Infrastructure is important for both the regional location of private industry and for the international competitiveness of the economy as a whole. Without roads or railways available to ship goods, without generous power sources, without accessible waste disposal sites, manufacturers could not be productive. The link between public infrastructure and private-sector productivity has been recently explored in the academic community by David Aschauer (1988, 1989a, 1989b and 1990) who examines the relationship between aggregate productivity and the stock and flow of government spending variables in the U.S. Using the restrictive assumption that the technology is Cobb-Douglas, Aschauer finds that public capital makes almost as significant a contribution as does private capital, and so argues that much of the decline in U.S. productivity during the 1970s was expedited by declining rates of public capital investment. Costa et al. (1987), using a translog production function and U.S. cross-section data, estimate the association between public capital and regional output, and find a positive role for public capital. These results have been confirmed by Deno (1988) who uses a translog profit function and regional U.S. data to conclude that public capital appears to play an important role in manufacturing firms' output supply and input demand decisions. However, Tatom (1993) has criticized this methodology and strongly questioned the infrastructure hypothesis. There is also the claim that the early estimates are not credible due to their extraordinarily large size [Berndt and Hansson, 1992]. When Aschauer did his regressions, he found estimates of production elasticity of government capital to be between 0.38 and 0.56, and when these values were used to compute rate of returns, the conclusion was that one unit of government capital pays for itself in terms of higher output in a year or less. This seems rather improbable. The suggestion is that the production function framework is inadequate because it omits input prices (which affect factor utilisation and so bias the estimated coefficients).

Using duality theory and estimating a cost function that incorporates public infrastructure as a fixed external input is an alternative approach which has been developed in the literature (Berndt and Hansson 1992, Lynde and Richmond 1992, Shah 1992, Conrad and

Seitz 1994, and Nadiri and Mamuneas 1994). All of these studies find that public infrastructure significantly enters the private-sector cost function. These results are intuitively appealing for two reasons. First, public capital investment should expand the productive capacity of a region by increasing regional resources. Second, infrastructure should enhance the productivity of existing resources. For example, a new network of roads, highways and sewers may attract firms to an industrial site, but those new roads will also allow existing manufacturers to truck their inputs and outputs more efficiently (less time on the road due to a more direct route, less wear and tear on trucks, etc.) Public capital increases the productivity of the private sector by reducing the cost of producing private-sector goods.

Canada's pattern of public investment has been similar to many industrialized countries since the 1960s. Public gross investment as a percentage of GDP peaked around 1975 (at approximately 4 percent) and declined thereafter (to under 3 percent by 1989). [(1)] Explanations for the relative decline in infrastructure spending are numerous: the oil crisis of the 1970s caused tax revenues to fall, and most countries experienced subsequent crippling inflation along with historically high real interest rates; the existence of burdensome budget deficits has meant that consumption spending, not investment spending, takes precedence on political agenda; and financial market fluctuations which caused uncertainties in the 1970s and 1980s could also have exacerbated the problem. Whatever the reasons, it is becoming clear that a public policy shift toward a greater concern for our current and future infrastructure is vital for Canadian economic growth and competitiveness.

The "evidence from the United States -- that public capital investments have significant private-sector payoffs -- [must be tested to see if it] is universally applicable. Fragmented evidence suggests that public capital has increased output and productivity in other OECD countries, but definitive conclusions must await more detailed investigations" (Munnell 1991: 23). This research attempts to fill this need and shed more light on the infrastructure/productivity link.

A constant elasticity of substitution-translog (CES-TL) variable cost model is used to capture the interaction of the public sector and private manufacturing sector, using Canadian provincial data from 1961 to 1992. The following sections specify theoretical and empirical frameworks to estimate provincial cost functions, report the results of the appropriateness of the CES-TL model, estimate elasticities of substitution, both in the short and long run, as well as cost elasticities, present estimates on the rates of return to fixed factors, and identify important provincial differences.

The Theoretical Model and Its Empirical Specification

Public capital is important for enhancing productivity and growth of the private sector. The economy's core infrastructure, public support of education and training, and the extent of technological innovation supported by the public sector are all important in reducing costs and improving private-sector performance. Providing these services often requires significant initial outlays and once the infrastructure is in place, extra consumers can be serviced at negligible marginal cost. This means that marginal cost pricing is not an efficient resource-allocation mechanism. The result is that these goods and services are viewed as "free" to private sector users. There is a price paid for the services through the tax system, but prices cannot be identified as market prices. If the private-sector production function is altered in some way by the quantity and quality of public infrastructure, then the usual production function must be altered to include these effects. We write the production function as:

$$Y = f\,(X_i,\ EF) \qquad (1)$$

where Y is the maximum output that can be produced in a time period, given quantities of the inputs X_1, X_2, ... X_n, and EF are the exogenous factors beyond the span of control of the producing unit. If equation (1) is a well-behaved neo-classical production function, there exists a cost function dual to the production function, having the general form:

$$C = g\,(Y,\ P_i,\ EF) \qquad (2)$$

where C is the total private cost of producing output Y, given that the input quantities X_i have been purchased at prices P_i, and that costs are also conditional on exogenous factors EF.

To implement the model empirically we specify four private factor inputs: labour, capital, energy and intermediate inputs (materials). As well, we identify two important exogenous factors that affect the cost relationship, the state of technical knowledge, and the amount of available public infrastructure, so the cost function is specified as:

$$C = g\,(Y,\ P_l,\ P_k,\ P_e,\ P_m,\ T,\ F) \qquad (3)$$

where C is total cost, Y is output, P_l, P_k, P_e, P_m are the prices of labour, capital, energy and materials respectively, T is an index of time representing disembodied technical change, and F is the (exogenous) stock of public infrastructure. We employ the CES-TL, introduced by Pollack, Sickles and Wales (1984), to estimate equation (3) which can be specified as:

$$lnC = lnC\ (Y,\ P_l,\ P_k,\ P_e,\ P_m,\ T,\ F)$$

$$a_o + \alpha_y lnY + 0.5\alpha_{yy}(lnY)^2 + \ln(\sum_{i=1}^{n} \alpha_i P_i^{(1-\sigma)})^{1/(1-\sigma)}$$

$$\cdot\ 0.5\sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} lnP_i lnP_j + \sum_{i=1}^{n} \gamma_{iy} lnY lnP_i + \sum_{i=1}^{n} \gamma_{it} lnT lnP_i \quad (4)$$

$$0.5\gamma_{tt}(lnT)^2 + \gamma_{yt} lnT lnY + \sum_{i=1}^{n} \gamma_{if} lnF lnP_i + 0.5\gamma_{ff} \ln(F)^2$$

$$+ \gamma_{yf} lnF lnY + \gamma_{tf} lnT lnF + \gamma_t lnT + \gamma_f lnF$$

where is the elasticity of substitution in the CES-framework, the a_o, $_i$'s, and $_i$'s are parametric constants and all other variables are as defined above.

Using Shephard's lemma we obtain the cost shares of the variable inputs as:

$$S_i = \frac{lnC(Y,\ P_l, P_k, P_e, P_m,\ T,\ F)}{lnP_i} = \frac{X_i P_i}{C}$$

$$= \gamma_{iy} lnY + [\alpha_i P_i^{(1-\sigma)}][\sum_{j=1}^{n} \alpha_j P_j^{(1-\sigma)}]^{-1} \quad (5)$$

$$+ \sum_{j=1}^{n} \gamma_{ij} lnP_j + \gamma_{it} lnT + \gamma_{if} lnF,\ i = 1,\ldots,n$$

The following restrictions imposed on equations (4) and (5) imply that the CES-TL cost function is well-behaved:

$$s.t.:\ \gamma_{ij} = \gamma_{ji},\ i \neq j;\ \sum_{j=1}^{n} \gamma_{ij} = \sum_{i=1}^{n} \gamma_{ji} = 0;$$

$$\sum_{i=1}^{n} \gamma_{iy} = 0;\ \sum_{i=1}^{n} \gamma_{it} = 0;\ \sum_{i=1}^{n} \gamma_{if} = 0;\ and \sum_{i=1}^{n} \alpha_i = 1. \quad (6)$$

This model is non-homothetic, and provides certain advantages over the TL system and its variants. However, the CES-TL: (1) combines the TL and the CES of the Arrow-Chenery-Minhas-Solow type, thus increasing the substitution possibility patterns as compared to substitution patterns implied either by the TL or the CES technologies; (2) includes, as special cases, both the TL production technology and the CES production technology; and (3) allows nested testing using the traditional statistical methods.

The parameter estimates from equations (4) and (5) are utilized to compute price elasticities which suggest pairwise substitutability of inputs, if positive, or complementarity, if the value computed is negative. These elasticities take the form:

$$
\begin{cases}
(\sigma-1)[\alpha_i P_i^{(1-\sigma)}][\sum_{i=1}^{n} \alpha_i P_i^{(1-\sigma)} - \alpha_i P_i^{(1-\sigma)}][\sum_{i=1}^{n} \alpha_i P_i^{(1-\sigma)}]^{-2} S_i^{-1} \\
\quad + [\gamma_{ii} + S_i(S_i - 1)] S_i^{-1}, \quad i = j \\
(\sigma-1)[\alpha_i P_i^{(1-\sigma)}][\alpha_j P_j^{(1-\sigma)}][\sum_{j=1}^{n} \alpha_j P_j^{(1-\sigma)}]^{-2} S_i^{-1} \\
\quad + (\gamma_{ij} + S_i S_j) S_i^{-1}, \quad i \neq j
\end{cases}
\tag{7}
$$

Global convexity of the cost function requires that all own-price elasticities, $_{ii}$'s, be negative at all points. No *a priori* restrictions are imposed on the cross-price elasticities.

Several other useful measures that characterize the cost structure under examination can be calculated. The total and average cost elasticities with respect to output are measured by equations (8) and (9) respectively:

$$
\frac{n C}{n Y} = \alpha_y + \alpha_{yy} \ln Y + \sum_{i=1}^{n} \gamma_{iy} \ln P_i + \gamma_{yt} \ln T + \gamma_{yf} \ln F \tag{8}
$$

$$
{}_{c/y} = \frac{\partial \ln(C/Y)}{\partial \ln Y} = \frac{\partial(\ln C - \ln Y)}{\partial \ln Y} = \epsilon_{cy} - 1 \tag{9}
$$

These elasticities can, among other things, be used to identify economies of scale. Long-run scale economies are the reduction of cost, as all inputs are

changed, but with constant input prices. [(2)] Measures of these economies of scale can be inferred from the elasticity of total cost; for example, a value of the total cost elasticity, equation (7), equal to, greater than, or less than unity implies constant, decreasing, or increasing returns to scale respectively. [(3)]

Ohta (1974) defines the dual rate of returns to scale as:

$$
\epsilon_{cy}^{-1} = \frac{1}{\epsilon_{cy}} \tag{10}
$$

and the dual of total factor productivity is the rate of cost diminution, computed as: [(4)]

$$\epsilon_{ct} = -\frac{\partial ln C}{\partial ln T}$$

$$- (\gamma_t + \sum_{i=1}^{n} \gamma_{it} ln P + \gamma_{tt} ln T + \gamma_{yt} ln Y + \gamma_{tf} ln F) \quad (11)$$

The primal rate of total factor productivity is then defined by Ohta (in its dual form) to be:

$$\epsilon_{tfp} = \epsilon_{cy}^{-1} \epsilon_{ct} \quad (12)$$

In addition to the above information on total factor productivity, average input productivities with respect to output are typically measured as Y/x_i. For example, output per man hour, and output per unit capital are usual average productivity measures. The average productivity elasticity, which captures the elasticity of the ith factor-specific average productivity with respect to the jth input price is:

$$_{ij} = \frac{\partial \mathbf{ln}(Y/X_i)}{\partial ln P_j} = - \epsilon_{ij} \qquad i,j = K,\ L,\ E,\ M. \quad (13)$$

Other factor-specific average productivity elasticities are the elasticity of average factor productivity with respect to changes in output:

$$\pi_{iy} = \frac{\partial \mathbf{ln}(Y/X_i)}{\partial \mathbf{ln} Y} = \mathbf{1} - \epsilon_{cy} - \gamma_{yi} S_i^{-1} \quad (14)$$

and the elasticity of average factor productivity with respect to changes in technology:

$$\pi_{it} = \frac{\partial \mathbf{ln}(Y/X_i)}{\partial ln T} = - \epsilon_{ct} - \frac{\gamma_{it}}{S_i} \quad (15)$$

We also obtain share elasticities by differentiating the logarithm of the cost function twice with respect to the logarithms of input prices: (5)

$$\tau_{pi} = \frac{\partial^2 ln\, C}{\partial ln\, P_i^2} = \gamma_{ij} \quad for \quad i = j \tag{16}$$

Also, differentiating the logarithm of the cost function twice with respect to the logarithms of the input prices and the level of output yields measures of biases of scale:

$$\tau_{yp_i} = \frac{\partial^2 ln\, C}{\partial ln\, P_i \partial ln\, Y} = \gamma_{iy} \tag{17}$$

If this scale bias is positive, the cost share of the factor input increases with a change in the level of output. If negative, the cost share decreases with a change in output, and if the scale bias is zero, the cost share is independent of the change in output. An equivalent alternative interpretation is that if this scale bias is positive, the cost flexibility increases with the input price. If negative, the flexibility of cost decreases with an increase in input price, and if zero, the cost flexibility is independent of input price.

Differentiating the logarithm of the cost function twice with respect to the level of output yields yet another piece of information about cost flexibility:

$$\tau_{yy} = \frac{\partial^2 ln\, C}{\partial ln\, Y^2} = \alpha_{yy} \tag{18}$$

If this parameter estimate is positive, negative, or zero, the cost flexibility is increasing, decreasing, or independent of the level of output.

Because the impact of public infrastructure on private-sector output is of primary importance to this research, we add the following elasticity calculations specific to the fixed public infrastructure component and computed in a way similar to the elasticities above:

$$\frac{n\, C}{n\, F} = \gamma_f + \gamma_{yf} ln\, Y + \sum_{i=1}^{n} \gamma_{fi} ln\, P_i + \gamma_{ff} ln\, F + \gamma_{tf} ln\, T \tag{19}$$

This elasticity is the saving in private production cost resulting from an increase in fixed public infrastructure, and the elasticity of average factor productivity with respect to changes in infrastructure is given by:

$$\pi_{if} = \frac{\partial \ln(Y/X_i)}{\partial ln F} = - \epsilon_{cf} - \frac{\gamma_{if}}{S_i} \qquad \textbf{(20)}$$

Finally, the estimated signs of the infrastructure/factor input interactive coefficients in the cost function will indicate whether infrastructure is a substitute of, or a complement to, individual factors of production.

Data Description and Estimation Procedure

The model described above is estimated for Atlantic Canada using provincial data (1961-1992) for the total of manufacturing industries. Data for the total cost of manufacturing, separated into the cost of fuel and electricity, cost of materials and supplies, the cost of labour, the cost of capital, and the value of output produced come from Statistics Canada (catalogue #31-203). The stock of public infrastructure series has been constructed using available data on mid-year net stock figures from Statistics Canada's *Fixed Capital Flows and Stocks*, *National Wealth and Capital Stock Section*, from 1961 to 1982. Then annual net provincial government investment in fixed capital (from Provincial Accounts, 1983-1992) is added to the stock figures to complete the series. The price of labour has been computed from the manufacturing series using information on the number employed and total salaries and wages paid. The price of materials is proxied by the Consumer Price Index for each province. The price of energy has been computed by calculating the total amount of energy consumed by the manufacturing industry in each province (in petajoules) from *Consumption of Purchased Fuel and Electricity by Manufacturing 1962-1978* (catalogue #57-506) and combining that series with a series published in *The Quarterly Report on Energy Supply-Demand in Canada* (catalogue #57-003) that reports petajoule use from 1978-1992. Data for the one missing year (1961) are interpolated based on a time trend estimated for pre-OPEC years. Finally, the price of capital has been computed using the following relationship: [(6)]

$$P_K = IP_K(1 + \theta + r) \qquad \textbf{(22)}$$

where P_k is the price of capital services, is the depreciation rate, r is the market rate of interest, and IP_K is the implicit price of capital for the manufacturing sector computed from *Fixed Capital Flows and Stocks* (catalogue #13-568). For estimation purposes, all prices have been normalized using base year 1986 equal to unity.

For CES-TL we assume additive error terms for cost and input-share equations. These error terms are postulated to have joint normal distributions with mean zero vector, [0,...0], and a constant variance-covariance matrix . The cost and share equations are jointly estimated by the method of Full Information Maximum Likelihood (FIML) contained in the *Shazam* (Version 7.0, 1993) econometric computer program. This technique maximizes the likelihood function for the entire system by choice of all parameters, subject to all a priori restrictions and gives consistent and asymptotically efficient estimators.

However, since the sum of the input cost-share equations is unity, the variance-covariance matrix will be singular. To avoid this, one of the input cost-share equations must be deleted from the estimation procedure. Thus, the FIML estimation procedure is applied to derive estimates of the parameters of the behavioral equations for the cost shares for labour, capital, and energy, and for the total cost equation. The estimates for the deleted equation (the cost share of intermediate inputs) are obtained by using the adding-up constraints.

Estimation Results

The parameter estimates of the CES-TL model for manufacturing firms by province from 1961-1992 are presented in Table 1. Interestingly, the CES version of the model does offer an improvement over the TL for three of the four provincial cost function estimates (the exception is Newfoundland). The coefficient, , is estimated to be different from 1 (and is statistically significant at the 5 percent level), and the nested test using the log-likelihood ratio supports the CES-TL version for Prince Edward Island (PEI), Nova Scotia and New Brunswick. [(7)] Therefore we find support for the hypothesis that the CES-

Table 1 Estimates of the CES-TL Model: Manufacturing in the Atlantic Provinces, 1961-1992

	NF		PEI		NS		NB	
	Estimate	T-Ratio	Estimate	T-Ratio	Estimate	T-Ratio	Estimate	T-Ratio
a_o	-1.232	-0.096	54.456	0.895	-146.61	-2.334	6.273	0.173
y	-5.615	-2.622	-19.723	-1.759	16.667	1.689	1.456	0.246
yy	0.587	2.404	2.611	2.346	-1.076	-1.396	-0.300	-0.602
	1.303	6.378	4.300	8.619	1.173	20.572	1.211	22.806
l	1.474	5.060	0.369	13.301	2.130	7.405	2.071	8.671
k	0.193	1.121	0.018	1.889	0.703	5.174	0.341	2.159
e	0.155	1.499	0.000	0.165	-0.016	-0.141	-0.267	-2.652
lk	-0.059	-0.737	-0.034	-3.2484	-0.249	-2.707	-0.139	-2.246
le	-0.129	-2.460	0.005	1.064	0.003	0.064	0.120	2.191
lm	0.352	2.035	-0.774	-8.378	0.636	4.042	0.394	2.924
ke	-0.035	-3.501	-0.012	-2.340	0.003	0.221	0.003	0.273
km	0.044	0.846	0.010	0.487	0.214	2.860	0.033	0.273
em	0.169	3.925	-0.000	-0.064	-0.010	-0.322	-0.050	-1.617
ly	-0.162	-7.175	-0.015	-1.398	-0.106	-5686	-0.103	-6.393
ky	0.011	0.416	0.045	3.428	-0.037	-1.966	0.016	0.836

ey	-0.020	-2.188		-0.020	-2.464		-0.014	-1.524		0.002	0.327
lt	-0.005	-2.691		-0.000	-0.104		0.005	5.049		0.005	5.819
kt	0.002	0.504		0.008	4.151		0.001	0.516		0.008	2.779
et	-0.002	-2.292		-0.002	-4.957		-0.002	-4.783		-0.004	-6.597
tt	-0.013	-3.548		-0.007	-2.456		-0.006	-2.289		-0.000	-0.060
yt	-0.011	-0.411		0.067	2.265		0.041	1.377		-0.022	-1.205
lf	0.079	4.989		0.000	0.023		-0.029	-4.334		-0.030	-6.439
kf	-0.014	-0.565		-0.046	-3.211		-0.000	-0.044		-0.043	-2.242
ef	0.017	2.301		0.015	3.676		0.021	5.593		0.026	6.108
ff	-0.521	-2.944		-0.053	-0.421		-0.361	-2.459		-0.173	-2.066
yf	-0.115	-0.679		-1.024	-3.644		-0.029	-0.144		0.288	1.767
tf	0.083	3.185		0.035	2.375		0.40	1.906		0.005	0.394
t	-0.772	-5.137		-1.141	-2.601		-1.078	-3.130		0.264	0.921
f	7.360	6.107		12.719	4.366		4.898	1.719		-1.977	-0.822

Note: NF: Newfoundland; PEI: Prince Edward Island; NS: Nova Scotia; NB: New Brunswick

TL is a superior model form in this situation. The parameter estimates further support the hypothesis that the non-homothetic assumption cannot be rejected due to the fact that 62.5 percent of the interactive terms between price and

Table 2 Price Elasticities of Input Demands

	NF			PEI			NS			NB	
	Estimate	T-Ratio		Estimate	T-Ratio		Estimate	T-Ratio		Estimate	T-Ratio
ll	-0.497	-1.063		-0.746	-1.274		-0.220	-0.810		-0.136	-0.185
kk	-0.834	-3.339[a]		-0.720	-4.187[a]		-0.877	5.009[a]		-0.482	-2.710
ee	-0.667	-1.173		-0.660	-3.830[a]		-0.748	-1.221		-0.945	-1.278
mm	-0.541	-1.219		-0.385	-3.022[a]		-0.265	-0.806		-0.136	-0.579
lk	0.430	1.284		-0.013	-0.188		0.249	0.430		0.205	0.516
kl	0.326	1.284		-0.012	-0.188		0.192	0.430		0.178	0.516
le	-0.711	-0.723		0.393	1.850[b]		0.117	0.098		0.132	0.116
el	-0.146	-0.723		0.052	1.850[b]		0.020	0.098		0.035	0.116
lm	0.168	0.456		0.178	1.270		0.084	0.320		-0.022	-0.102
ml	0.317	0.456		0.707	1.270		0.245	0.320		-0.077	-0.102
ke	-0.282	-1.526		-0.374	-1.655[b]		0.183	0.541		-0.160	-0.617

ek	-0.077	-1.526	-0.053	-1.655[b]	0.040	0.541	-0.049	-0.617
km	0.192	1.804[b]	0.178	5.680[a]	0.155	1.246	0.083	1.113
mk	0.480	1.804[b]	0.785	5.680[a]	0.588	1.246	0.326	1.113
em	0.180	3.279[a]	0.212	2.263[a]	0.026	0.490	0.076	1.503
me	1.661	3.279[a]	0.641	2.263[a]	0.447	0.490	0.972	1.503

Note: a. indicates statistical significance at 5 percent.

b. indicates statistical significance at 10 percent.

output ($_{iy}$'s) are statistically significant. In addition, the regularity conditions are satisfied for the majority of the data points (85 percent of the data points generated strictly convex isoquants in the neighbourhood covered by the data set). [(8)] Also, since the cost-share equations are estimates of the share that each of the factor inputs has of total costs, the model generates predicted mean shares. These estimated shares have been compared to the actual cost shares in the data set using a two-tailed test of the difference between two means. No significant differences between the estimated shares and the actual shares are found at the 5 percent significance level. We are therefore confident that the model results (CES-TL) can be used to generate the required elasticity information. [(9)]

Table 2 presents the estimated price elasticities. All own-price elasticities of input demand are negative as required, although some of them are not statistically significant at the 5 percent level. These results are not surprising due to the nature of manufacturing in the Maritimes. Manufacturing is a relatively small sector in each of the Atlantic provinces, and the resulting modest scale is not likely to be large enough to afford a large number of substitution possibilities, nor allow for a great deal of responsiveness to price changes.

The following discussion focuses on the remaining measures that are estimated to be statistically significant. The cost elasticity measures for each of the provinces (Table 3) indicate that over the 1961-1992 time period substantial economies of scale were present, ranging from PEI's 2.9 to New Brunswick's 1.2. [(10)] Newfoundland and Nova Scotia generated identical results of 1.4. The rate of cost diminution is not a statistically significant estimate for any of the provincial cost functions, implying no substantial disembodied technical change took place over this time period. Therefore, the annual gains, as estimated by the rate of total factor productivity, are due to the exploitation of economies of scale. The estimate of -0.119 for Newfoundland implies costs were reduced by 0.11 percent per year due to productivity gains, output and prices constant. The rate of total factor productivity estimate is similar for PEI. However, Nova Scotia and New Brunswick experienced considerably smaller gains (0.05 percent and 0.02 percent respectively). What technological advances there have been, have been labour-saving (the estimated factor bias effect has a negative sign) for all provinces. Technology has been capital-saving for PEI and New Brunswick, and materials-saving for PEI and Nova Scotia. For PEI, Nova Scotia and New Brunswick, technology has been energy-using.

Technology has been capital, energy and materials neutral in Newfoundland, capital neutral in Nova Scotia, and materials neutral in New Brunswick.

Due primarily to the economies of scale present in the Maritime manufacturing sector, the average rate of factor productivity for labour has been increasing as output expands for each province. As well, PEI has experienced increases in average factor productivity rates for every input. This result is entirely consistent with the extremely high estimate of economies of scale. Energy productivity in Newfoundland, and capital and energy productivity in Nova Scotia have improved. Output expansion has not altered the rate of

Table 3 Econ. of Scale, Total Factor Productivity (TFP) and Factor-Specific Productivity Measures

		NF		PEI		NS		NB	
	Coeff.	Est.	T-Stat	Est.	T-Stat	Est.	T-Stat	Est.	T-Stat
Cost elasticity:	cy	0.698	4.543[a]	0.345	2.242[a]	0.694	4.816[a]	0.843	8.524[a]
Econ. of scale:	cy^{-1}	1.433	--	2.899	--	1.441	--	1.186	--
Rate of cost diminution:	ct	-0.083	-0.890	-0.042	-0.650	-0.035	-0.566	-0.015	-0.238
TFP (in dual form):	tfp	-0.119	--	-0.122	--	-0.050	--	-0.018	--
Average productivity elasticity w.r.t. output:									
	ly	0.925	8.381[a]	0.746	8.425[a]	0.823	7.374[a]	0.728	7.351[a]
	ky	0.247	1.577	0.363	3.326[a]	0.539	3.873[a]	0.056	0.425
	ey	0.675	3.480[a]	1.104	5.361[a]	0.714	2.477[a]	0.112	0.750
	my	-0.046	-0.474	0.686	13.64[a]	0.044	0.656	0.020	0.378
Average productivity elasticity w.r.t. tech.:									
	lt	-0.062	-3.728[a]	-0.041	-3.474[a]	-0.613	-6.780[a]	-0.044	-4.812[a]
	kt	-0.093	-2.178[a]	-0.093	-2.588[a]	-0.440	-1.185	-0.065	-2.355[a]
	et	-0.042	-1.543	0.060	2.425[a]	0.031	1.752	0.068	4.039[a]
	mt	-0.095	-5.376[a]	-0.034	-4.356[a]	-0.028	-3.274[a]	-0.001	-0.129
Share elasticities:									

	pl	-0.174	-1.442	0.803	8.261[a]	-0.390	-3.356[a]	-0.375	-2.821[a]
	pk	0.040	0.791	0.036	1.309	0.032	1.164	0.186	3.684[a]
	pe	0.058	1.961[a]	0.007	1.869[b]	0.004	0.230	-0.073	-2.066[a]
	pm	-0.502	-2.309[a]	0.771	9.122[a]	-0.836	-4.249[a]	-0.450	-2.610[a]
Factor bias effects of technological change:									
	lt	0.045	2.473[a]	-0.041	-3.474[a]	-0.061	-6.780[a]	-0.044	-4.812[a]
	kt	-0.011	-0.282	-0.093	-2.588[a]	-0.044	-1.185	-0.065	-2.355[a]
	et	0.000	0.000	0.060	2.425[a]	0.031	1.752[b]	0.068	4.039[a]
	mt	-0.006	-0.366	-0.034	-4.356[a]	-0.028	-3.274[a]	-0.001	-0.129
Factor bias effects of scale:									
	ply	-0.162	-7.175[a]	-0.015	-1.398	-0.106	-5.686[a]	-0.103	-6.393[a]
	pky	0.052	0.416	0.008	3.428[a]	-0.037	-1.967[a]	0.016	0.836
	pey	-0.020	-2.188[a]	-0.010	-2.464[a]	-0.014	-1.524	0.002	0.327
	pmy	0.013	2.240[a]	0.017	2.361[a]	0.157	2.870[a]	0.085	1.267
Cost flexibility:	yy	0.587	2.404	2.610	2.346[a]	-1.076	-1.396	-0.300	-0.602

Note: a. indicates statistical significance at 5 percent.

b. indicates statistical significance at 10 percent.

average productivity of either private capital or materials use in Newfoundland, nor materials use in Nova Scotia, nor has it changed the productivity rate of anything but labour in New Brunswick.

For Newfoundland, the share elasticity estimate for energy is positive, and for material it is negative. Capital's and labour's share elasticity estimates are not significantly different from zero. This indicates that energy's share of total cost will rise in response to proportional changes in input prices, but material's share of total cost will fall, and labour's and capital's share will remain neutral. In PEI, labour, energy and material shares will increase, and capital's share will remain neutral. Nova Scotia manufacturing will see labour's and material's shares fall, energy's share increase, and capital's share remain neutral. Finally, in New Brunswick, labour's share, energy's share and material's share will drop, while capital's share will rise. In response to output increases, the negative sign on $_{ply}$ (for example, Newfoundland) indicates that labour's cost share will decrease. As Newfoundland production increases, labour's share and energy's share will decrease, material's share will increase, and capital's cost share will remain neutral. For PEI, where the scale effects are largest, we see labour's share remaining neutral, capital's and material's share increasing, and energy's share falling. In Nova Scotia, labour's and capital's share falls, material's share increases, and energy's share remains neutral. In New Brunswick, the province with the smallest scale economies, capital's, energy's and material's cost shares will remain neutral, while labour's share will decrease. Cost flexibility in Newfoundland and PEI increases with the level of output, more so for PEI. For Nova Scotia and New Brunswick, cost flexibility is independent of the level of output.

Finally, we turn to an examination of the impact of public infrastructure on manufacturing costs. [(11)] The cost elasticity measures the "productivity effect" of public-sector infrastructure. As reported in Table 4, the values for Newfoundland, PEI, Nova Scotia and New Brunswick (-0.481, -0.156, -0.237 and -0.115) are much smaller (with the exception of Newfoundland) than the estimates reported by Aschauer (1989) for the U.S. economy. However, Aschauer used a production function approach. Our values are similar to the results of Nadiri and Mamuneas (1994) who use a TL cost function approach for U.S. data and find cost elasticities ranging from -0.11 to -0.21 for the twelve industries studied. Our statistically significant estimates strongly support the idea that public infrastructure spending plays an important role in private manufacturing productivity. The costs of the Maritime Provinces' manufacturing sectors will be significantly decreased due to increases in public-sector infrastructure. [(12)]

We also find statistically significant factor bias effects as well as significant impacts on average factor productivity when infrastructure levels are changed. In Newfoundland, public capital is labour and energy using, materials saving and capital neutral. Also, average factor productivities with respect to infrastructure all decline when public capital increases. Public capital is labour neutral, capital saving, and energy and material using in PEI, As well, the average productivity of labour, energy and materials declines as infrastructure

Table 4 The Impact of Public Infrastructure on Atlantic Canada's Manufacturing Costs

		NF		PEI		NS		NB	
	Coef.	Est.	T-Stat	Est.	T-Stat	Est.	T-Stat	Est.	T-Stat
Cost Elasticity:	cf	-0.481	-3.584[a]	-0.156	-1.973[a]	-0.237	-2.721	-0.115	-2.004[a]
Factor bias effects of public infrastructure:									

	lf	0.079	4.989^{a}	0.000	0.023	-0.029	-4.334^{a}	-0.030	-6.439^{a}
	kf	-0.014	-0.565	-0.046	-3.211^{a}	-0.000	-0.044	-0.043	-2.242^{a}
	ef	0.017	2.301^{a}	0.015	3.676^{a}	0.021	5.593^{a}	0.026	6.108^{a}
	mf	-0.082	-2.466^{a}	0.031	2.104^{a}	0.008	3.042^{a}	0.047	6.246^{a}
Average productivity elasticities w.r.t. infrastructure:									
	lf	-0.784	-9.950^{a}	-0.158	-1.938^{b}	-0.096	-2.382^{a}	0.514	1.766^{b}
	kf	-0.411	-2.889^{a}	0.141	1.423	-0.231	-1.847^{b}	0.157	1.262
	ef	-0.793	-5.158^{a}	-0.857	-4.354^{a}	-0.847	-7.258^{a}	-0.649	-7.151^{a}
	mf	-0.314	-3.976^{a}	-0.203	-5.651^{a}	-0.251	-6.096^{a}	-0.191	-5.340^{a}

Note: a. indicates statistical significance at 5 percent.

b. indicates statistical significance at 10 percent.

increases. In the province of Nova Scotia, public capital is labour saving, capital neutral and energy and materials using. Average productivities also decline. New Brunswick results imply that infrastructure is labour and capital saving, energy and materials using. Also, labour productivity is enhanced, but energy and materials productivity decreases.

Summary and Conclusions

This paper has had a number of purposes. We have sought to add to the understanding of the cost characteristics of Altantic Canadian manufacturing, we have examined the effects of public infrastructure on provincial manufacturing costs, and we have compared the results generated for this Canadian region with results from the U.S.

Maritime manufacturing costs from 1961-1992 are characterized by economies of scale. As well, factor input demands are generally price inelastic, and factors are pairwise substitutes. Our findings relating to public infrastructure are very strong. We find statistically significant infrastructure cost elasticities that indicate productivity effects for public capital in each province. We also find that infrastructure has an impact on manufacturing cost characteristics. The services of public capital are substitutes to the services of private capital in PEI and New Brunswick, and have a neutral impact on the services of private capital in Newfoundland and Nova Scotia. There are also provincial differences in other factor bias effects of public infrastructure, and average factor productivity has been diminished in most cases as public capital has increased.

Lynde and Richmond (1992) and Nadiri and Mamuneas (1994) found complementarity between private and public capital for their U.S. data. This differs from our results for the Atlantic Provinces. However, both of these studies found statistically significant cost elasticities, as did we.

In future work, we plan to study the impact of different types of infrastructure on industry level data. This will allow a better understanding of the provincal differences reported here.

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Endnotes

1. Graphs illustrating public investment as a percentage of GDP for OECD countries from 1967-1990 can be found in Munnell (1991: 29).

2. See, for instance, Christensen and Greene (1976), and Gillen and Oum (1984).

3. For further analysis, see Pindyck (1979) and Andrikopoulos et al. (1989).

4. See Berndt and Khaled (1979), and Brox (1993).

5. For details of this measure as well as the following two calculations, see Jorgenson (1986).

6. See Field and Grobnstein (1980). Also, Berndt and Hansson (1992: 158) add that, in many cases, assuming that the marginal corporate tax rate is zero may be a realistic assumption.

7. We also tested the CES-TL against the CES alternative and tested the non-homotheticity assumption using similar nested log-likelihood tests. In all cases the unrestricted CES-TL was supported by the data. Details of these tests are available from the authors on request.

8. The method used to test the regularity conditions is that employed by Pollak *et al*. (1984). For the cost function to satisfy regularity conditions, its Hessian matrix: $[\partial^2 lnC/\partial p_i p_j]_{ij}$ of second-order derivatives with respect to variable input prices should be negative semi-definite. The results found in this study are not unusual as such flexible functional forms frequently fail to satisfy these theoretical requirements. See Diewert and Wales (1987).

9. In addition to the tests reported above, one could test for a disequilibrium/dynamic structure of the system and for structural change in the rate of technological change as well. Such tests will be the focus of future research.

10. The size of the scale economies, especially for PEI are quite large, which may be indicative of sub-optimal scale of operation in the very small Atlantic manufacturing sector. The scale of the manufacturing sector as measured by the ratio of manufacturing shipments to GDP ranges from a low of 0.22 in PEI to a high of 0.52 in New Brunswick. This compares to a value of 0.64 in Ontario.

11. In addition to the results discussed below, we ran the nested log-likelihood test on the assumption that all coefficients involving terms with public infrastructure effects be restricted to equal zero. The data rejected this assumption in all cases.

12. For example, if public capital were increased by 10 million constant dollars, total manufacturing costs would be estimated to fall by $1.73 million in Newfoundland, $0.54 million in PEI, $2.05 million in Nova Scotia, and $1.16 million in New Brunswick.