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Highway Infrastructure Capital and Productivity Growth: Evidence from the Canadian Goods-Producing Sector

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I. Introduction

Does investment in public infrastructure stimulate national and regional economic growth? Can a link be quantified between public investment in infrastructure and private sector productivity? Are results robust to different specifications? These issues have received much attention from economists, regional scientists, and transport planners and continue to concern policy makers.

The literature on these issues began with the work of Aschauer (1989 a,b) and has been further explored by a number of researchers including Munnell (1990), Deno and Eberts (1991), Morrison and Schwartz (1992), Hulten and Schwab (1984, 1991), Garcia-Mila and McGuire (1992), Holtz-Eakin (1994), Mullen and Williams (1992), and Moomaw, Mullen and Williams (1995) among others for the United States. Wylie (1995) examined the issue for Canada using time-series data for total infrastructure. The focus of this research has been on public infrastructure as a whole, or specific components such as highway, sewer and water and other infrastructure. There is no published research for Canada which has used panel data and highway capital stock as an input. The objective of this paper is to examine the impact of highway capital stock in Canadian provincial goods-production using panel data.

Most research on this topic has used a production function approach which optimizes input utilization given fixed prices (i.e profit maximization). A few studies have utilized a cost function approach which optimizes input utilization given fixed output (i.e. cost *minimization*). In the production function approach, a Cobb-Douglas functional form is usually used to estimate the association between private sector economic growth and public infrastructure capital or investment. A time series, or cross-section of observations, on the aggregate level of private sector output is regressed against observations on the aggregate level of labour and capital employed by the private sector and public infrastructure capital.

The impact of public infrastructure on private sector output is measured by its elasticity: the percentage change in output resulting from a one percent change in public infrastructure capital, keeping the levels of private labour and capital fixed.

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In the literature, the reported elasticities of output with respect to changes in **infrastructure capital** are ***very diverse***.

Although the existence of an important link between public infrastructure and private sector economic growth and productivity are widely recognised, there is much controversy concerning the size and significance of the relationship.

Aschauer (1989), using aggregate time series data, estimated output elasticities with respect to public capital ranging from 0.39 to 0.56. Munnell (1990a) reported an elasticity of 0.33 for labour productivity with respect to public capital. The magnitude of these estimated elasticities and their associated marginal products are generally considered to be extraordinarily large. The primary criticism of Aschauer's finding was that the sizeable elasticity merely reflected a spurious correlation between output and the public capital stock, and that once one controlled for nonstationarity of the national time series the relationship disappeared (Tatom 1991). McGuire (1992) and Eisner (1991) have argued that the empirical evidence from the aggregate time-series data is not compelling.

Researchers turned to panel data (i.e. time-series and cross-sectional) to improve their estimation procedure. Based on state level data, Munnell (1990 b) estimated a regional level output elasticity of public capital of 0.15 compared to her national-level estimate of 0.33 for the United States. A number of other studies using state level data confirm that aggregate public capital (as well as individual components such as highway, sewer and water, and other infrastructure) has a positive and statistically significant effect on regional economic performance. On the other hand, Hulten and Schawab (1991a) and Tatom (1991) used a panel of region level data and did not find any statistically significant relationship between the growth rate of productivity and infrastructure capital growth at the regional level.

What are the sources of diverging results? Research has identified five sources of divergence: the degree of aggregation; use of different technique; error in model specification; use of different functional form; and error in variable measurement.

Eakin (1994) argued that proper specification of the error structure was not investigated in previous econometric studies, and is the apparent source of conflicting evidence using state level data. He recommended inclusion of time and state specific characteristics in the estimating equation. Moomaw, Mullen and Williams (1995) argued that a translog functional form, rather than a Cobb-Douglas functional form, should be used, as the Cobb-Douglas specification assumes the output elasticity of public capital is constant. In other words, the Cobb-Douglas specification does not permit an interstate comparative analysis, while the translog specification does. Moomaw, Mullen and Williams (1995) used a translog specification but did not capture the state-specific and time-specific effects in their estimation.

This paper utilizes a new set of data on Canadian public highway capital stock. It investigates the robustness of empirical results by using both Cobb-Douglas and translog functional forms. In addition, we incorporate time and province-specific effects in our analysis.

The present analysis offers several variations on Eakin's study (1994). We provide province by province empirical evidence for the association between highway capital and goods-producing sector output, rather than an estimate for the "average" province in the sample. We estimate provincial goods-producing production functions using both Cobb-Douglas and translog specifications with highway capital, private capital and private labour as the three inputs. Translog specification permits the estimation of the output elasticity of highway capital for each province and year. Panel data from 1961-1994 for 10 Canadian provinces are used to estimate the input coefficients of the production function, and to assess the nature of the interaction between highway capital and other inputs.

Section II of the paper presents the methodology, and discusses the issues of specification and estimation of the production function and nonstationarity of variables. Section III discusses the data and estimation results. Section IV concludes.

II. Methodology

This paper uses an aggregate **production function** to model the role of highway capital in provincial goods-production as:

$$Y_{pt} = \lambda * F(K_{pt}, L_{pt}, H_{pt}) \qquad (1)$$

where p represents province, t represents time period, Y is real output, λ represent the level of technology, K is goods-producing private capital stock, L is goods-producing labour input, and H is the highway capital stock. One of the benefits of building or maintaining a road is that it allows, at the margin, the goods-producing firm to raise output without increasing their own capital or labour input, or level of technology. This effect would be captured by a positive marginal product of highway capital.

To estimate the production function in equation (1) for Canadian goods-production, a generalized Cobb-Douglas specification is chosen. Alternately, a translog form is also explored, which allows us to estimate not only the marginal product of inputs, but also the substitutability and complementary between them.

The generalized Cobb- Douglas form based on equation (1) can be represented as:

$$Y_{pt} = \lambda * K_{pt}^{\alpha k} L_{pt}^{\alpha l} H_{pt}^{\alpha h} \varepsilon_{pt} \tag{3}$$

where αk represents the output elasticity of private capital, αl is the output elasticity of private labour, αh is the output elasticity of highway capital, and ε is the error term. The elasticity coefficients measure the percentage change in output for a given percentage change in factor inputs (private capital, private labour, highway capital).

Restating equation (3) in logarithmic-linear form yields the estimating equation:

$$\ln Y_{pt} = \ln \lambda + \alpha k \ln K_{pt} + \alpha l \ln L_{pt} + \alpha h \ln H_{pt} + \varepsilon_{pt} \tag{4}$$

An aggregate production function of the type in equation (4) has been estimated in the literature. The estimated elasticity coefficients (for public capital and its individual components such as highways) range from 0.04 to 0.20 depending on the set of data employed and the specification of the estimating equation. In an attempt to investigate the robustness of the estimates to differences in error specification and nonstationarity of data, several variations of equation (4) are estimated.

Specification and Estimation

1. One approach to the specification of the error structure when dealing with cross–section and time-series observations is to adopt a cross-sectional heteroskedastic and time-wise autoregressive model[1].

2. A second approach is to introduce time and/or province-specific dummy variables and estimate by OLS.

3. A third approach is the error component model. The basic assumption is that the regression error is composed of three independent components; one component associated with time, another associated with the cross sectional units, and the third varying in both dimensions.

This paper uses the first two approaches to check for the existence and importance of province as well as time specific effects in the estimation of the aggregate production function in equation (4). To allow for province and time specific effects, equation (4) can be rewritten as:

1 Pooling with the Kmenta model. The pooling technique described in Kmenta [1986, Section 12.2, pp. 616-625] employs a set of assumptions on the disturbance covariance matrix that gives a cross-sectional heteroskedastic and timewise autoregressive model. The POOL command in SHAZAM provides features for estimating this model.

$$\ln Y_{pt} = \ln \lambda + \alpha k \ln K_{pt} + \alpha l \ln L_{pt} + \alpha h \ln H_{pt} + u_p + v_t + w_{pt} \quad (5)$$

where u_p is a province-specific component, v_t is a time-specific component and w_{pt} varies in both dimensions. The u_p capture unobservable characteristics of the production function in each province that are omitted from the equation but do not vary over time. On the other hand, v_t control for shocks to the production function that are common to all provinces in each time period. The properties of the estimators of the equation depend on whether the time effect (v_t) and the province effect (u_p) are specified as fixed or random. If these are assumed to be fixed, the dummy variable model is appropriate. It permits the intercept to capture the province effects and the time effects respectively. If province and time effects are assumed to be random, the error component model is appropriate for estimation because it takes explicit account of the variation over time and provinces in a random manner. Helms (1985) suggests that it is more appropriate to treat both the time and state effects as fixed in interregional studies. In this study we assume both the time and province effects are fixed.

The equation (5) is estimated using three different specifications: (5.1) a GLS specification assuming a cross-sectional heteroskedastic and time-wise autoregressive model; (5.2) an OLS specification with fixed time effects, which is common in the literature; (5.3) a dummy variable model where both province and time effects are assumed to be fixed.

Nonstationarity of Data

Use of a panel data set reduces the likelihood that data is nonstationary. If data is nonstationary the positive elasticity coefficients which emerge from estimation may reflect spurious correlation. To avoid the problem of nonstationarity the production function is estimated in first-difference form, a specification commonly used to address nonstationarity. Equation (5) is rewritten in first difference form as:

$$\nabla \ln Y_{pt} = \alpha_0 + \alpha k \nabla \ln K_{pt} + \alpha l \nabla \ln L_{pt} + \alpha h \nabla \ln H_{pt} + u_p + v_t + w_{pt} \quad (6)$$

where $\nabla \ln Y_{pt}$ means the first difference of $\ln Y_{pt}$. Equation (6) is estimated using three different specifications: (6.1) an OLS specification with no time or province effects; (6.2) an OLS specification with fixed time and no province effects. (6.3) an OLS specification with fixed time and province effects.

Translog Production Function

The Cobb-Douglas functional form assumes constant and unitary elasticity of substitution across inputs. But a more flexible functional form allows input substitutability to vary. Are inputs substitutes or complements in the goods-production process? The translog production function has a non-linear relationship between output and factor inputs which includes cross product terms indicating the substitutability or complementary of the inputs. This functional form does not impose a restriction of constant output elasticities, allowing a comparative analysis of output elasticities (across provinces) with respect to highway capital[2].

The translog specification of equation (4) can be written as:

$$\ln Y_{pt} = \alpha_0 + \alpha_l \ln L_{pt} + \alpha_k \ln K_{pt} + \alpha_h \ln H_{pt} + \frac{1}{2}\alpha_{ll}(\ln L_{pt})^2 + \frac{1}{2}\alpha_{kk}(\ln K_{pt})^2$$
$$+ \frac{1}{2}\alpha_{hh}(\ln H_{pt})^2 + \alpha_{lk}\ln L_{pt}\ln K_{pt} + \alpha_{lh}\ln L_{pt}\ln H_{pt} + \alpha_{kh}\ln K_{pt}\ln H_{pt} \quad (7)$$
$$+ u_p + v_t + w_{pt}$$

The equation (7) is estimated using three different specifications as in the Cobb-Douglas case: (7.1) an OLS specification with no time and province effects; (7.2) an OLS specification with fixed time effects and no province effects; (7.3) and an OLS specification with fixed time and province effects.

III. Data and Empirical Results

Data

The goods-producing sector includes agriculture, forestry, fisheries, mines, quarries and oil wells, manufacturing, construction and other utilities. Real provincial output and labour input in the goods-producing sector are obtained from the Conference Board of Canada. Capital stocks for the goods-producing sector are from Statistics Canada's Fixed Capital Stocks and Flows series (end year, net stocks, based on geometric depreciation, in constant 1986 dollars). Highway capital stocks are obtained from Statistics Canada by special tabulation (end year, net stocks, based on geometric depreciation, in constant 1986 dollars).

Results from Cobb-Douglas Production Function

Table 1 presents estimates of the Cobb-Douglas production function of equation (5)[3]. Column (5.1) presents GLS estimates showing that highway capital stock is a significant contributor to goods-producing output, with an elasticity of 0.12.

2 Mullen and Williams have estimated output elasticities with respect to highway capital stock across states for U.S.A for the three years (1992,1995).

3 We estimated both unconstrained and constrained equations. We impose the constraint of constant returns to scale (CRTS) in a) private inputs, and b) in all inputs. The null hypothesis that the estimated production functions exhibits CRS has rejected in both instances. We only present here estimates from the unconstrained equation due to space restriction.

This indicates that a 1% increase in highway capital would raise goods-producing output by 0.12 percent.

Table 1
Estimated Parameters
Cobb-Douglas Production Function

Variables	(5.1)	(5.2)	(5.3)	(6.1)	(6.2)	(6.3)
				First Difference		
	Elasticity Estimates			Elasticity Estimates		
	GLS	Fixed Time Effect OLS	Fixed Province & Time Effect OLS	OLS	Fixed Time Effect OLS	Fixed Province & Time Effect OLS
Labour	0.76*	0.62*	0.65*	0.44*	0.62*	0.65*
	(0.04)	(0.06)	(0.07)	(0.04)	(0.06)	(0.06)
Private Capital	0.23*	0.31*	0.22*	0.42*	0.31*	0.30*
	(0.04)	(0.03)	(0.05)	(0.02)	(0.03)	(0.03)
Highway Capital	0.12**	0.10	0.14**	0.17*	0.09	0.08
	(0.07)	(0.07)	(0.08)	(0.06)	(0.07)	(0.07)
R^2	.995	.998	.998	.973	.980	.981
SE	0.064	0.064	0.053	0.072	0.064	0.064

Note: * Significant at 5% level, Standard Error of the estimates in parentheses
** Significant at 7% level

Column (5.2) shows an OLS specification with fixed time effects comparable to many of the early estimates of state-level production functions with public capital as an input (e.g. Munnell (1990 b) and Garcia-Mila and McGuire (1992))[4]. Column (5.3) displays an OLS specification with fixed time and province effects.

Controlling for time, but not province effects, the estimated coefficient of highway capital is 0.10, positive and insignificant. Once we control for time and province effects the estimated coefficient of highway capital is 0.14, positive and significant.

4 Munnell (1990b) does not use time-effects, instead including the unemployment rate as a measure of cyclical conditions.

Table 1 also presents regression results of equation (6) where the variables are in first differences form, as an adjustment for nonstationarity[5]. Column (6.1) presents an OLS specification where highway capital is a significant contributor to the goods-producing output, with an elasticity of 0.17. In column (6.2) an OLS specification with fixed time effects shows an estimated elasticity for highway capital of 0.09, positive and insignificant. Column (6.3) displays an OLS specification with fixed time and province effects with an estimated elasticity for highway capital stock of 0.08, positive and insignificant.

Results from Translog production Function

Estimates of the translog production function of equation (7) are presented in Table 2. Column (7.1) presents an OLS specification with no fixed time and province effects, showing an estimated coefficient of highway capital of 0.10, positive and insignificant. Once we control for fixed time effects in column (7.2) the estimated coefficient of highway capital is 0.14, positive and significant. The coefficients of the cross-product terms of labour and highway capital are positive and significant, indicating that they are complements, whereas the coefficients of the cross product terms of private capital with both labour and highway capital are negative and significant, indicating that they are substitutes. When we control for both fixed time and province effects in column (7.3) we see a large, positive and significant coefficient for highway capital with the substitutability and complementary relationships between inputs as in column (7.2).

Table 3 summarizes the output elasticities and associated marginal products[6] of highway capital of an average province. The output elasticities of highway capital, range from 0.08 to 0.36 and the associated marginal products of highway capital range from 0.36 to 1.20. The magnitude of the highway elasticity estimates vary substantially based on error specification of the estimated equations, use of functional forms and estimation technique. *Our first conclusion is that highway capital has a positive and generally significant effect on Canadian provincial goods-producing output for various specifications of the error structure and functional forms.*

5 When we apply the Augmented Dickey-Fuller test to the data, we reject the hypothesis of nonstationarity of variables at the 5% level.

6 The marginal product of highway capital is equal to the output elasticity of highway capital multiplied by the ratio of output to highway capital stock, calculated from both equations (5) and (7) as: $\frac{\partial Y_{jt}}{\partial H_{jt}} = \frac{\partial \ln Y_{jt}}{\partial \ln H_{jt}} * \frac{Y}{H}$. It measures the dollar change in goods-producing output resulting from a dollar change in highway capital at the margin.

Table 2
Estimated Parameters
Translog Production Function

Coefficient	(7.1) OLS	(7.2) (OLS) Fixed Time-effect	(7.3) (OLS) Fixed Time & Province effect
α_0	0.07	0.07	-0.11
	(0.50)	(0.62)	(0.13)
αk	0.41*	0.20*	0.19*
	(0.05)	(0.03)	(0.06)
α_l	0.56*	0.78*	0.60*
	(0.06)	(0.07)	(0.09)
α_h	0.10	0.14**	0.36*
	(0.09)	(0.09)	(0.10)
α_{kk}	0.02	0.09*	0.04
	(0.03)	(0.03)	(0.03)
α_{ll}	-0.53*	-0.38*	-0.13
	(0.10)	(0.09)	(0.10)
α_{hh}	-0.70*	-0.48*	-0.10
	(0.18)	(0.17)	(0.19)
α_{kl}	0.06	-0.04	-0.01
	(0.09)	(0.08)	(0.10)
α_{kh}	-.20**	-0.31*	-0.12
	(0.12)	(0.11)	(0.11)
α_{lh}	1.40*	1.20*	0.43**
	(0.24)	(0.23)	(0.27)
R^2	.997	.998	.998
SE	0.06	0.05	0.05

Note: In the translog production function α_h is not the elasticity of output w.r.t highway capital. Elasticity of output is calculated from eq. (7) as: $\frac{\partial \ln Y_{pt}}{\partial \ln H_{pt}}$

Standard Error of the estimates in parentheses
* Significant at 5% level
** Significant at 8% level

Table 3
Summary Results of Elasticity and Marginal Product

Pool Cross–Section & Time–Series Analysis			
Highway elasticity estimates (α_h)		**Marginal product ($\frac{\partial Y_{pt}}{\partial H_{pt}}$)**	
Cobb–Douglas Production Function			
GLS	0.12	GLS	0.51
Fixed time	0.10	Fixed time	0.43
Fixed time & province	0.14	Fixed time & province	0.60
OLS*	0.17	OLS*	0.69
Fixed time*	0.09	Fixed time*	0.38
Fixed time & province*	0.08	Fixed time & province*	0.36
Translog Production Function			
OLS	0.13	OLS	0.63
Fixed time	0.17	Fixed time	0.87
Fixed province & time	0.36	Fixed province & time	1.20

Note: The output elasticity of highway capital is derived from equation (7) as $\frac{\partial \ln Y_{pt}}{\partial \ln H_{pt}}$ and marginal product of highway capital is computed as $\frac{\partial Y_{pt}}{\partial H_{pt}} = \frac{\partial \ln Y_{pt}}{\partial \ln H_{pt}} \bullet \frac{Y}{H}$

* First difference

Province Specific Results

The results presented above are for the "average province". But is there variation among provinces? Table 4 presents output elasticities of highway capital for each province over four years[7]. Elasticities of output with respect to highway capital are mostly positive and ranges from -0.06 to 0.29 over time[8]. Table 4 also shows that highway capital is contributing less and less to output over time with the exception of British Columbia and Ontario. For most provinces the decline in output elasticity of highway capital occured in the period of the 1960s to early 1970s, corresponding to rapid highway construction. The more modest output elasticities of highway capital in the 1980s and 1990s reflect the relatively mature highway networks in place. The increasing output elasticities for highway capital in Ontario and British Columbia (and their relatively high values compared to

7 Results are presented for an OLS specification with fixed time effects (7.2), because results based on this specification are statistically more significant than the others. Results from other specifications are also available upon request.

8 Negative values of the elasticities for some states are reported in the literature. Helms, L. Jay, (1985) and Moomaw, Mullen and Williams (1995).

other provinces) perhaps reflects the continued strong population and economic growth in these provinces which might be outpacing the development of their respective highway networks.[9] *Our second conclusion is that with very few exceptions, the output elasticities with respect to highway capital for each province and time period demonstrate a positive, but diminishing contribution to provincial goods-producing output.*

Table 4
Output Elasticities of Highway Capital Stocks

	Elasticity of Highway Capital			
Province	**1972**	**1978**	**1984**	**1990**
Alberta	0.288	0.271	0.049	-0.005
British Columbia	0.058	0.197	0.117	0.188
Manitoba	0.098	0.100	0.132	0.036
New Brunswick	0.195	0.045	-0.008	0.053
Newfoundland	-0.063	0.070	0.090	0.183
Nova Scotia	-0.008	0.055	0.133	0.080
Ontario	0.123	0.163	0.131	0.139
Prince Edward Island	0.023	0.092	0.142	0.087
Quebec	0.189	0.116	0.070	0.040
Saskatchewan	0.236	0.106	-0.052	-0.088

IV. Conclusions

This paper investigates the role of highway capital in Canadian goods production. We estimate province-wide production functions using both Cobb-Douglas and translog functional forms with highway capital, private capital and labour as the three inputs. Several specifications of Cobb-Douglas and Translog production function are estimated. In order to provide a more detailed assessment of the role of highway capital a comparative analysis across province and time are conducted.

Generally, highway capital has a positive contribution on provincial goods producing output. This relationship holds for the various specification of the error structure and functional forms. Highway capital and private capital are found to be substitutes. Highway capital and labour are found to be complements. The size and significance of the estimates vary depending on specification of the equation, type of data used, and on the use of functional forms.

9 We make no attempt to explain the relatively large output elasticity for Newfoundland for 1990. This estimate fell to a more modest value of 0.03 to 0.04 in 1992-1993.

The conclusion that highway capital contributes to private output is obtained within a narrow framework, that being estimation of province-level Cobb-Douglas and translog production functions. It is clear that this approach does not exhaust all possible methods for examining the linkage between highway capital and productivity. For example, this approach does not allow for lags in the impact of highway capital on private output, nor does it allow for network effects, whereby the quality of the connections facilitated by investment in highway infrastructure may be more important than the level of the capital stock.

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* Eakin should be read as Holtz-Eakin

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