A Review of Studies on the Relationship between Transport Infrastructure Investments and Economic Growth

Research conducted for the Canada Transportation Act Review

Report prepared by
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EXECTIVE SUMMARY

The benefits and importance of transportation infrastructure to economic growth have been recognized for a long time. There is little doubt that investments in transportation systems (roads, railways, and canals) stimulated economic development in North America in the 19th century. No one living in contemporary North America can overlook the profound changes brought about by the Interstate Highway System in the U.S.A. and the Trans-Canada highway in Canada. Transportation infrastructure has expanded the range over which goods can be marketed. It has made production and distribution process more efficient, created opportunities for economies of scale and increased specialization, changed logistic systems and reduced costs. These all benefit economic productivity.

Theoretical arguments and historical evidence have shown a strong linkage between transportation infrastructure investments and economic productivity. However, most economic studies on this topic look at the rates of return of individual infrastructure projects by calculating all the benefits and costs of projects. It was not until the late 1980s that economists started to develop quantitative measures of such linkage by building macro-econometric models. In 1989, Aschauer initiated such an attempt in a series of studies (Aschauer 1989a, b, c, 1990a, b). The pioneering work of Aschauer has attracted numerous studies on this topic in the past decade. Aschauer employs a Cobb-Douglas production function and uses aggregated national time series data for the U.S. to investigate the relationship between public infrastructure capital and aggregated output of the private sector. He finds a very strong and high-level linkage between these two variables. Even the return to public capital is much higher than the one to private capital. The estimated elasticity of output with respect to the public capital is 0.39, meaning that a 1 percent increase in the capital stock increases output in the private sector by 0.39 percent. The elasticity of the 'core' infrastructure including highways, mass transit, airports etc. is about 0.24. Munnell extends Aschauer's work and reaches the same conclusion. The results of the studies are said to provide an explanation of the slowdown in productivity growth in developed countries after 1973, which was caused, at least partially, by the deficiency of public capital.

A large number of researchers have re-examined or further explored the relationship between public infrastructure capital and economic growth. However, as many studies point out, these estimates are likely to have overstated the magnitude of the impact of public infrastructure investment on private sector output and productivity growth. It also does not make sense for public capital investment to have a substantially greater impact on private sector output than private capital investment. In order to mitigate some problems that have arisen from the time series studies, subsequent studies are based on pooled time series and cross-section data. The results indicate a smaller and weaker contribution of public infrastructure investments and that the composition of infrastructure capital matters; some type of infrastructure (e.g. core infrastructure including highway, water and sewer system etc) may have greater effect than others.

There are serious problems in studies using both time series data and panel data in production function approach. Spurious correlation (non-stationarity) easily results in significant and substantial coefficients between infrastructure capital and economic output. Trying to remove the non-stationarity by first-differencing runs the danger of focusing on the short relationship between these two variables, which is not the primary purpose of these studies. There also is no clear direction of causation. Does the estimate suggest that economic growth is caused by infrastructure investment or a region with larger output or when a fast growing economy can afford to build more in infrastructure capital? Our review shows that the estimated results are largely dependent upon econometric formulation. Simpler econometric specifications always have large estimates and they are statistically significant. A sophisticated regression then makes such estimates much smaller and weaker, sometimes negative, and often insignificant.

More recently, some researchers have employed a cost function approach to investigate the effect of public infrastructure capital on the productivity. Cost function approach seems better suited to this analysis as it has many conceptual and econometric advantages over production function approach. Interestingly, there have been consistent conclusions on the relationship between public infrastructure capital and productivity growth in the cost function based analysis. The evidence from this approach suggests that infrastructure investments contribute significantly to growth in output, reductions in cost, and increases in profitability although the contribution is much smaller than what some production function based studies reported. Such contributions in most studies are also smaller than that of private capital.

However, this evidence is largely based on manufacturing industries. When an attempt is made to extend it to overall economy, its theoretical foundation is debatable.

Except for enormous studies using data for the U.S., there are several attempts using data for Canada. The results obtained by studies in the Canadian context show almost the same pattern to those in the U.S. Aggregate time series studies report elasticity of productivity with respect to the public capital or highway capital about 0.40. Adjustment by first difference then shows it has been reduced to barely 0.08 and a statistically very weak significance. Panel data studies with more sophisticated econometric formulations do not even support the argument that infrastructure capital significantly contribute to economic growth. The cost function approach, however, shows that such relationship does exist, though the magnitude is much smaller (the cost elasticity ranges 0.07-0.22).

The controversial evidence from studies we reviewed leave room open to discuss policy implications. If highway infrastructure has substantial benefits to productivity growth, does this imply that the infrastructure is undersupplied and higher levels of investment are warranted? If the infrastructure investment has very weak or no contribution to productivity growth does it suggest that the provision of road networks, bridges, water supply systems etc does not play any role in economic growth?

However, the review suggests that at least two sets of policies could be simultaneously given attention. One is to look specifically at the quality of services and the potential utilization of existing transportation infrastructure through a range of management measures. An emphasis is made on the efficient use, design, and management of transportation infrastructure. The other is to elaborate the future needs for transportation infrastructure capital to potential growth of the economy and the spatial distribution of economic activities. For an individual transportation infrastructure investment decision however, the macro studies are not able to provide specific guidance. These require microeconomic tools, such as social cost-benefit analysis.

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INTRODUCTION

The benefits and importance of transportation infrastructure to economic growth have been recognized for a long time. There is little doubt that investments in transportation systems (roads, railways, and canals) stimulated economic development in North America in the 19th century. No one living in contemporary North America can overlook the profound changes brought about by the Interstate Highway System in the U.S.A. and the Trans-Canada highway in Canada. Transportation infrastructure has expanded the range over which goods can be marketed. It has made production and distribution process more efficient, created opportunities for economies of scale and increased specialization, changed logistic systems and reduced costs. These all benefit economic productivity.

Fox (1990) has formulated a general regional economic model of aggregate supply and aggregate demand to analyze conceptual relationships between infrastructure investments and output. Transportation infrastructure investments can expand the productive capacity of a region, both by increasing resources and by enhancing the productivity of existing resources. First, transportation infrastructure can enter in the production process as a direct input and in many cases as an unpaid factor (e.g. the transportation services that highways provide). Second, infrastructure may make other existing inputs more productive. A well-constructed highway allows goods to be transported to market in less time, hence enabling private companies to produce their products at lower total cost. Third, it may act as a magnet or catalyst of regional economic growth by attracting resources from other regions. This is the so called "agglomeration effect". On the other hand, transportation infrastructure may affect economic output by changing aggregate demand. Transportation infrastructure construction can create and increase demand for intermediate inputs from other sectors and stimulate multiplier effects in the economy. Public infrastructure can also influence output by crowding in or out private inputs (labor and private capital). An increase in public infrastructure investment could attract more private investments if there is a complement relationship between them; or it could reduce private investments when public capital has a substitute effect on private inputs.

Theoretical arguments and historical evidences have shown a strong linkage between transportation infrastructure investments and economic productivity. Yet, most economic studies on this topic look at the rates of return of individual infrastructure projects by calculating all the benefits and costs of projects. It was not until the late of 1980s that economists started to develop quantitative measures of such linkage by building macro-econometric models. In 1989, Aschauer initiated such an attempt in a series of studies (Aschauer 1989a, b, c, 1990a, b). The pioneering work of Aschauer has attracted numerous studies on this topic in the past decade. Aschauer employs a Cobb-Douglas production function and uses aggregated national time series data for the U.S. to investigate the relationship between public infrastructure capital and aggregated output of the private sector. He finds a very strong and high-level linkage between these two variables. Even the return to public capital is much higher than the one to private capital. By a similar approach, Munnell (1990a) reaches the same conclusion. The results of the studies provide an explanation of the slowdown in productivity growth in developed countries after 1973, which was caused, at least partially, by the deficiency of public capital.

A large number of researchers have re-examined or further explored the relationship between public infrastructure capital and economic growth. Instead of using time series data, Munnell (1990b) makes use of pooled time series and cross-section data, mitigating some problems of time series data. She also disaggregates the public infrastructure into core infrastructure (highway, water and sewer systems) and others, and examines the impact of each individual type of infrastructure. Many studies follow this approach but undertake more sophisticated econometric analysis (Eisner, 1991; Evans and Karras, 1994; Holtz-Eakin, 1994, Moomaw, Mullen and Williams, 1995; Khanam 1996; Waters, 1999). Some studies use a translog function to further look at the relationship between private and public capital and to answer questions such as whether public capital is crowding out private capital. Recently, Fernald (1999) has assessed the link between highway capital and productivity using industrial sector breakdown instead of cross-state data and found that vehicle-intensive industries benefit disproportionately from road-building capital.

Most of the above studies estimate a production function. More recently, a cost function approach has also been employed by many researchers (Lynde and Richmond, 1992; Morrison and Schwartz, 1996; Nadiri and Mamuneas, 1996; Khanam, 1999). Cost function is suggested as being even better suited to this kind of analysis because it avoids the possible correlation between public and private capital (Gillen, 1996). Interestingly, the studies using a cost function approach are more consistent in reaching the conclusion that highway infrastructure capital has significant and positive effects on economic growth.

This report will be a review of studies on the linkage between public and transportation (particularly highway) infrastructure investments and economic growth. We focus largely on the empirical research undertaken over the past decade. Such research has been based on the formulation of macro-econometric models. After providing some basic facts about the public and highway capital in Canada and in the United States, two studies (Aschauer 1989a and Munnell 1990b) will be extensively examined as they are the starting point of the empirical literature. Then we explore a large number of subsequent studies that use different function forms, different types of data, different industries and especially different econometric specifications. For example, time series data vs pooled time series and cross-section data, aggregated estimation vs disaggregated estimation, and production function approach vs cost function approach. Not surprisingly, those studies have reached different and controversial conclusions. Critical reviews of technical problems in the literature will be presented in each section. The findings and conclusions will be summarized and their policy implications will be discussed. Particularly, there are several studies (Lynch, 1994; Wylie, 1995; Khanam 1996, 1999; Waters, 1999) in the Canadian context and we include them in the review.

FACTS ABOUT PUBLIC AND HIGHWAY INFRASTRUCTURE CAPITAL

The macro-econometric studies use either public (infrastructure) capital or its components separately as independent variable(s). The major one is highway infrastructure capital. Intangible capital owned by the public sector such as human capital investment and/or research and development capital are not included. Our analysis on public capital is based on the data from Statistics Canada (StatsCan), Cat. # 13-568, Fixed Capital Flows and Stock. The data source for U.S is from Munnell (1992).

StatsCan has compiled data for total public and private capital combined, by province and also by sector. For a measure of total public infrastructure capital for all 10 provinces, we here use the sum of capital for three public sector accounts: "government service industries," "education service industries," and "health and social service industries." There may be a relatively small amount of private sector capital in these accounts, but this measure is dominated by public capital. Private capital is obtained by subtracting public capital from the total capital.

Table 1: Public Infrastructure Capital in Canada, 1993
(C$ billions in constant 1992 price)

Total private capital	409.37
Total public capital	134.38
Government service	94.41
Highway	37.60
Education service	24.33
Health & social service	15.64
Total Capital	543.75

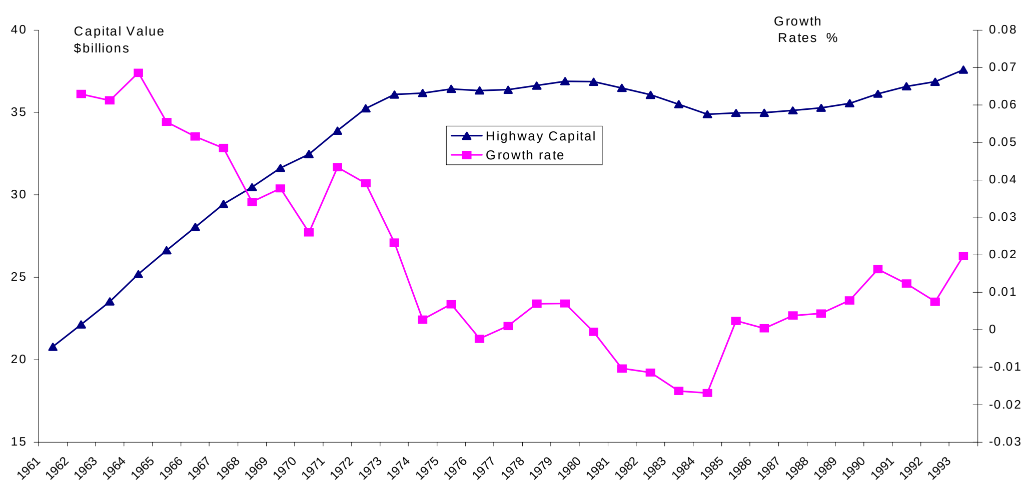
Sources: Statistics Canada and Transport Canada

There is also some public capital included in private capital but the magnitude is not substantial. All kinds of capital are non-resident capital and are constructed using the "perpetual inventory method". We use figures for geometric depreciation, valued at 1992 prices. The data for highway capital stock in the period of 1961-1993 was estimated by the Special Infrastructure Project of Statistics Canada and Transport Canada and we incorporate the data into our analysis.

Table 1 reports the stock of total public capital in Canada that was $134.4 billion in 1993, or about one third the size of the private capital . Among the public capital, government service accounted for 70 percent and the other 30 percent went to education, health and social service combined. With regards to the highway capital, it valued at $37.6 billion, taking a share of 28 percent of total public capital, or accounting for 40 percent of total capital stock of government service industries. Highway capital alone is almost the same size as those of combined education, and health and social service industries.

Figure 1 shows that the years before 1973 were the golden time of highway construction with long time sharp increases of capital stock. Dramatic drops of the growth rates occurred in 1973 and the years following. This was worse in the economic recession of the early 1980s. At

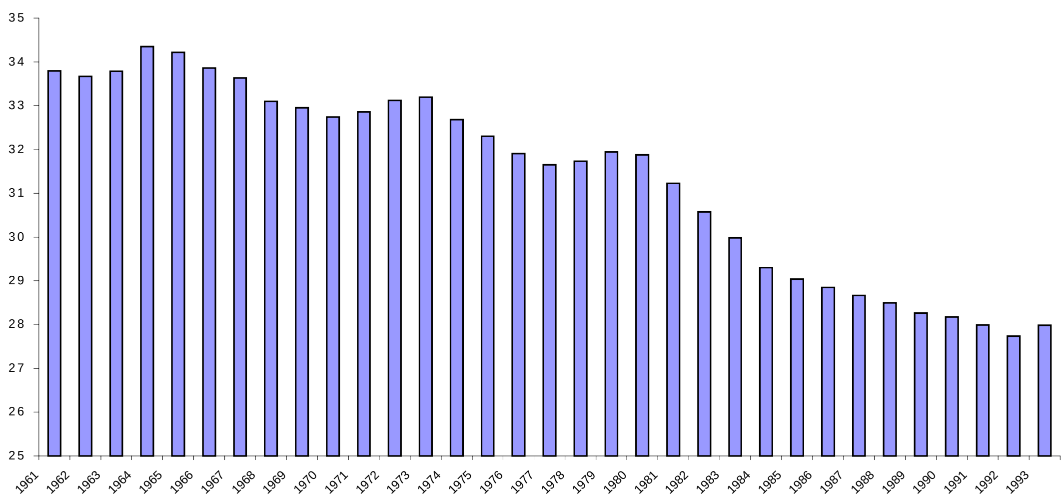
Figure1: Highway Capital Stock and Growth Rates



that time not only were growth rates declining, but the absolute value of total highway capital was experiencing losses. The total public capital has experienced a similar pattern. Because these two time declines of highway capital coincided the economic recessions, it is not surprising that simple time series analyses find a correlation between the public (highway) capital stock and overall economic growth. The highway investments decreased even more compared to the total public capital (Figure 2). The share of highway capital in the total public capital was basically around one third in the 1960s and gradually declined to 28 percent in 1993.

In the United States, the public capital stock is very large, US$2.7 trillion in 1991 (current price) or about one-half the size of the private capital stock, according to data from the U.S. Bureau of Economic Analysis. About US$2.2 trillion of that public capital is nonmilitary. Highway capital accounts for 32 percent of the nonmilitary public capital, which is almost the same as the share occupied by education, hospital and other building capital (30 percent). This is basically the same pattern shown in Canada. The changes of public capital and highway capital in the U.S. in the past decades do not differ from those in Canada (see Gramlich, 1994 for detailed discussion on the U.S. data).

Figure 2: Percentage of Highway Capital in Public Capital



AGGREGATE TIME SERIES STUDIES

Modern macro-econometric studies on the roles of public infrastructure investments in economic growth dates back to a series of studies undertook by Aschauer (1989a, 1989b, 1989c, 1990a, 1990b). The pioneering paper of Aschauer (1989a) employs aggregate time series data to investigate the relationship between public investment and economic growth by expanding the conventional production function to include the public capital or its components. The expanded function form is written as:

$$Q = A * F(L, K, G)$$

Where Q is economic output, A is a measure of total factor productivity or Hicks-neutral technical change, L is the labour force, K is the stock of private capital and G is the public capital stock. Using Cobb-Douglas production function form and writing the above equation in logs gives:

$$LnQ = LnA + aLnL + bLnK + cLnG$$

Where a, b, c can be explained as the elasticity of output with respect to labour, private capital and public capital respectively. An assumption of constant return to scale across all factors leads to a+b+c=1. The rate of return (marginal product, MP_G) of the public capital or its components can be obtained by the following equation:

$$MP_G = c * Q / G$$

Aschauer (1989a) uses private business output/private capital ratio as the dependent variable and assumes the constant return to scale across all inputs. The estimated function form is then as follow:

$$LnQ - LnK = LnA + a(LnL - LnK) + c(\ln G - LnK)$$

Using data for the period 1949 to 1985, he finds a strong positive relationship between output per unit of capital input, the private labour-capital ratio, and the ratio of the (nonmilitary) public capital stock to the private capital input. The estimated elasticity of output with respect to the public capital is 0.39, meaning that a 1 percent increase in the capital stocks increases output in the private sector by 0.39 percent. Given the size of the nonmilitary public capital stock (US$1938 billion in 1991) and private business output (US$4800 billion), this translates to a marginal productivity of public capital of almost 100 percent. That is, a $1 increase in the public capital stock would raise output by another $1. Compared to the private capital, these figures show that "increases in GNP resulting from increased public infrastructure spending are estimated to exceed those from private investment by a factor of between two and five (Aschauer, 1990b)."

Further, Aschauer (1989a) explores the effects of the components of nonmilitary public capital stock on productivity. However, he only finds that the so-called 'core' infrastructure (highways, mass transit, airports, electrical and gas facilities, water, sewers) accounting for 55 percent of total nonmilitary public capital has a significant effect on the private business output. The estimated elasticity is about 0.24 and that is still very high. The coefficients of other components (e.g. hospitals, education buildings etc.) are insignificant different from zero.

Munnell (1990a) also uses aggregate time series data and a Cobb-Douglas production function with an assumption of constant return to scale across all inputs. Instead of using output/private capital ratio, she uses more familiar labour productivity (output labour ratio where labour is measured as hours worked) as the dependent variable and extends the data to 1987. She confirms Aschauer's finding that public capital does indeed belong in the production function. Both total nonmilitary public capital and core infrastructure enter with coefficients similar to those found by Aschauer and are generally statistically significant. The coefficients of 0.33 to 0.39 reported in her study imply that a 1 percent increase in public capital would raise labour productivity by 0.31 to 0.39 percent.

Aschauer and Munnell argue that their findings provide another explanation of the productivity slowdown in the North America and other developed countries after 1973. Before that, the analysis of productivity decline is concentrated on the increase in energy prices, the falloff in research and development expenditures, the migration of workers from farm to nonfarm occupations, social regulations and so on. It is not until Aschauer (1989a) that did the potential importance of public infrastructure capital in explaining the productivity slowdown emerge. The studies show that much of the decline in productivity in the U.S. and other industrial countries that occurred in the 1970s was precipitated by declining rates of public capital investment, particularly highway and other transportation infrastructure investments. Munnell (1990a) goes further, arguing that the drop in labour productivity has not been due to a decline in the growth of some mystical concept of multifactor productivity or technical progress. Rather, it has been due to a decline in the growth of public infrastructure.

The results of Aschauer and Munnell, however, are not unquestioned. Many subsequent studies challenge that the estimated effects of public capital stock on economic productivity using aggregate time series data are the result of spurious correlation. Even the relationship between public capital and output may go another way, i.e. higher levels of output lead to greater public capital investment. Other critics also suggest that the estimated elasticities are implausibly high and some important variables (e.g. energy price) may be excluded from the production function.

Spurious Correlation. One of the most frequently mentioned problems by many other studies is the spurious correlation or unrelated common trends between public investment and productivity decline. Many macro economic time series demonstrate the characteristic of non-stationarity, i.e. data series, will tend to 'drift' in similar directions over time. The estimates based on the non-stationary series without proper adjustment, therefore, may lead to spurious correlation, or unrelated common trends in the data over time. Aaron (1990) argues that time-series data are not very useful for examining the effects of public capital because there is insufficient variation in the data. To demonstrate his views, Aaron re-estimates a model similar to Aschauer's except for the introduction of dummy variables in 1966 and 1974. Infrastructure goes from being highly significant in the Aschauer specification to insignificant in Aaron's, leading to the conclusion that the infrastructure finding is not very robust and is dependent on limited variation.

In order to determine the true relationship between these two variables, it is necessary to first test the variables for stationarity and co-integration, i.e., to examine not only whether variables grow over time, but also whether they grow together over time and converge to their long-run relationship, and then adjust them before estimating the relationship. A common way to adjust is to take "first difference," using the change in a variable from one time period to the next rather than the absolute level of the variables. The studies that follow this approach, however, find much smaller, some times negative, and generally statistically insignificant coefficients (Hulten and Schwab, 1991; Tatom, 1991, 1993; Harmatuck, 1996). But Munnell (1992) argues that first-differencing destroys any long-term relationships which is the whole point of studying infrastructure and economic growth. She further points out that no one would expect the growth in the capital, whether private or public, on one year to be correlated with the growth in output in that the same year.

Causality. Eisner (1991) raises the issue that the estimated effects may be running another way, and that increased private output raises the demand for public infrastructure capital. A number of studies have used the Granger test to examine the direction of causality between public infrastructure and output. Duffy-Deno and Eberts (1991) provide regional evidence suggesting that causality runs both ways. Holtz-Eakin (1994) finds some ambiguity in the direction of causation. But Tatom (1993) does a series of lead-lag tests that indicate causation may be more from output to infrastructure capital. If the causality runs both ways then single equation production function techniques for quantifying the influence of public capital may have yielded biased coefficients.

PRODUCTION FUNCTION APPROACH USING PANEL DATA

Munnell (1990b) can be regarded as a starting point for making use of pooled time-series and cross-section data. Several subsequent articles made use of the private and public capital stock data created by her. Because no data are available for the stock of private or public capital on a state-by-state basis in the U.S., she has created the data under certain assumptions. For example, in the case of public capital, the approach taken is to create a state capital series based on annual state public investment data and BEA (Bureau of Economic Analysis) depreciation and discard schedules, and use this distribution of capital to apportion the existing BEA public capital totals. She specifies both Cobb-Douglas and Translog functions. The data used are for 48 states over the years 1970 to 1986. Using the Cobb-Douglas function, elasticities of 0.15 and 0.06 of gross state product to public and highway capital stocks are reported, respectively. The corresponding coefficients for the translog function are 0.16 and 0.04, respectively. All are positive and significant. In her models, no fixed or random effects are specified and her estimation procedures appear to be ordinary least squares (OLS). No first difference estimates are considered. The pooled data is organized in an uncommon way (she takes first the 48 different state observations for one year, and then 48 state observations for the next year, and so forth.) so that the Durbin-Watson (DW) statistic was not measured properly, i.e, a DW value of around 2 is shown but it was misleading. If there is autocorrelation, OLS estimation results are usually biased. Furthermore, either fixed or random effects must be taken into account when panel data are used.

Eisner (1991) tries to replicate the work of Munnell (1990b) using OLS procedures. First, under the exact same assumptions and specifications, he got almost identical results to Munnell (1990b) but very low DW values since the data is rearranged in the normal way (take time series or yearly observations for each state). However, the previous relationship disappears in the fixed state effect model and the first difference model. Only in the fixed time effect model is the public infrastructure coefficient significantly positive. He concludes on the one hand that those states that have more capital have greater output and on the other hand, no evidence is found that states with more public capital one year than another have more output during the year with more public. One noteworthy point is that DW values in Eisner (1991) are all very low, suggesting serial correlation exists and has not been corrected. Therefore, the OLS results cannot be taken seriously.

Using the same data as Munnell (1990b), Evans and Karras (1994) undertake a more complete study. One step is correcting for serial correlation. They argue that Munnell (1990) is likely to be misspecified because the models are estimated in levels and the data contain stochastic trends. They estimate Cobb-Douglas functions under different specifications. First, with OLS on levels, they find significantly positive elasticities. They then run OLS on levels with estimated state and time fixed effects, but providing no evidence that government capital has positive productivity. These runs, however, should not be taken seriously as the DW values are very low. Next, they correct for autocorrelation, differentiate the error terms and so on, and find no evidence to support the positive relationship between output and public capital, but in most times a negative relationship. They suggest that these results may still be biased because the coefficients for labour are unusually high. An alternative approach is used but the conclusion is the same. They point out that one could estimate a large and apparently statistically significant elasticity of output with respect to government capital if one does not account for fixed effects. But such results would be misleading, merely reflecting the fact that large states have large capital stocks, but this does not prove causality.

Holtz-Eakin (1994) reaches the same conclusions as Evans and Karras (1994) using similar data. First his OLS results show positive and significant coefficients. But the results are substantially different when the estimation is done by specifying fixed cross section effect, error term differences, random component and instrumental variables etc, i.e. the coefficient for public infrastructure is essentially zero. He argues that previous findings of large, positive effects appear to be the artifact of an inappropriately restrictive econometric framework.

Moomaw, Mullen and Williams (1995) estimate a translog function based on Munnel (1990) data. However they use information on the cross section of states at various points in time (1970, 1980 and 1986) rather than information contiguous in time as Munnell and others use. They argue that translog function is more appropriate than the Cobb-Douglas function as it avoids the bias inherent in a Cobb-Douglas specification, which yields the same constant elasticity for each state. The translog specification permits the retrieval of numerical estimates of the output elasticity of public capital for each state. No state-specific and time-specific effects are captured in their translog function; OLS procedure is used in the estimation. A significant and positive coefficient of aggregate public capital is found but the coefficient of highway capital is negative although insignificant. With regards to the elasticity, their conclusion is that, generally, aggregate public capital and highway capital make a positive contribution to state output. But the absence of state-specific effects could mean that this is a spurious relationship being estimated.

Duffy-Deno and Eberts (1991) use a simultaneous equations approach to estimate annual data for 28 metropolitan areas from 1980 through 1984. This is the only attempt among the studies to incorporate causality running other ways into estimations. They construct a simple model of both the effects of local public infrastructure on personal income and the effect of personal income on the allocation of local public outlays. Estimation procedures are OLS and 2SLS. Fixed time and cross section effects are captured. The result reveals that public capital stock has positive and statistically significant effects on per capita personal income, supporting Munnell's findings.

Many other studies using pooled time series and cross-state (region) data provide controversial results. Barcia-Mila and McGuire (1992) specify a regional production function that, in addition to labour and private capital, includes two publicly provided inputs – highways and education. They employ a panel data set consisting of annual observations on the 48 states from 1969 to 1983 to estimate input elasticity coefficients under a specification that allows for differences over time and across states. They find that both highways and education have a significant and positive effect on output with an estimate of 0.045 for highways, a little bit smaller than that reported by Munnell (1990b). Aschauer (1990a), using state level data during the period 1960 to 1985, and a measure of 'highway capacity' finds that the stock of highways is an important contributor to economic growth (with an estimated elasticity of 0.13). However, Hulten and Schwab (1992) suggest a weak link between public capital and economic performance in the manufacturing industry.

More recently, Fernald (1999) assesses the link between highway capital and productivity using industrial sector breakdown instead of cross-state data. Based on the Cobb-Douglas production function, he estimates the average TFP (total factor productivity) growth for each of 29 industries. He then runs the regression of the change in TFP on the change in the service of the road stock incorporating the average vehicle share of each sector. Using industry data from 1953 and 1989, he finds that vehicle-intensive industries benefit disproportionately from road-building capital. First, the slowdown in productivity after 1973 appears larger in industries with higher vehicle shares. Second, when road growth rises, productivity growth tends to rise relative to the average in vehicle-intensive industries. He also concludes that roads are exceptionally productive before 1973 but are not exceptionally productive at the margin, consistent with simple network arguments: building an interstate network might be very productive, but building a second network may not. In addition, he explores the empirical importance of congestion and the result shows that congestion does not appear important empirically before 1973, but becomes important thereafter.

In addition to using cross-state or cross-industry data, some other studies (Ford and Poret, 1991; Levine and Renelt, 1992; Canning and Fay, 1993; Taylor-Lewis, 1993; Sanchez-Robles, 1998) examine cross-country evidence as Aschauer (1989b) does early on. However, like those using cross-state data, they are mixed support of Aschauer results.

The use of pooled time series and cross-section or panel data mitigates some of the problems arisen in aggregate time series studies, such as extraordinarily large output elasticities. Because panel data takes advantage of greater variation in the infrastructure capital and other independent variables over space as well as time, the estimates indicate that the effect is much smaller. Nevertheless, Gramlich (1994) argues that it may still overstate the impacts of public infrastructure by confounding intrinsic state productivity differences with variation infrastructure capital. This approach is still subject to the problem of causality. It is not clear that the direction of causation runs from infrastructure capital to output; it can easily happen the other way.

Notice that when using the panel data, either fixed effect model (fixed time effect, fixed cross-section effect or both fixed time and cross-section effects) or random effect model must be specified. Holtz-Eakin (1994) argues that cross-section or panel-data studies are flawed when they fail to account for difference across states in factors such as weather, availability of raw materials, location and land area. Therefore the average influence of any one state relative to a designated base state must be removed by specifying fixed state effect. Similarly, fixed time effect removes the influence of the average differences of data for a specific year from that of a specified base year. Interestingly, reported results above in this section show that if these time and cross-section specific effects are ignored, public capital does appear to have a strong positive effect on output, and vice verse. For example, Munnell (1990b) does not estimate fixed or random effects models, and thus these estimates are subject to an important specification bias.

COST FUNCTION APPROACH

More recently, some researchers have moved to a cost function approach and argue that the cost function is preferable to the production function for both conceptual advantages and econometric reasons. The production approach is a purely technical specification of the relationship between inputs and outputs and not a behavior one. In this approach, the firm's optimization decisions with respect to how much output to produce and what mix of inputs to use in the production process are not considered specifically. The cost function approach takes, however, explicit account of the firm's optimization behavior by considering both inputs and outputs as endogenous variables, while input prices, which are market determined and thus considered beyond the immediate control of the firm, are the only exogenous variables. Without price data, which do not enter the production function, it is difficult to say whether a efficient choice has been made concerning the various inputs, in particular public capital. Furthermore, a cost-function-based analysis facilitates the explicit exploration of cost efficiency. This allows researchers to determine the effects of public infrastructure capital through a measured "rate of return" specified in terms of cost-saving benefits at a given output level.

Econometrically speaking, cost function approach avoids the multi-collinearity problem that may result in estimated coefficient biases because multi-collinearity is usually more of a problem with input quantities than with factor prices. The causality problem, difficult to be overcome in the production function approach, does not arise in the cost function methodology as the prices of inputs rather than their quantities are exogenous. Also, using a cost function allows us to impose linear homogeneity in factor of prices on our models. Imposing such restrictions, if they are reasonable, is the same as using additional information when making an estimate and, therefore, reduces the variance of an estimator. Imposing linear homogeneity on the production function, unfortunately, is the same thing as assuming constant returns to scale.

It should be noted, however, that cost functions require the assumption of an optimal mix of inputs (Oum, Water and Yu, 1998). While debatable, this is more plausible for applications to individual firms (micro data) than to aggregate or even industry-level data.

To examine the effects of public infrastructure on the cost of production in the private sector, a traditional cost function can be modified to include the public infrastructure service. Therefore the general form of the cost function can be written as:

$$C = C(w, Y, T; H)$$

Where C is total cost, w is the vector of prices of private inputs (usually labour, private capital, materials etc.), Y is the quantity of output, T is a measure of technical change and H represents public infrastructure service (the quantity of public capital stock).

The shadow value (B_h) or marginal benefits of the public capital can be obtained by taking the negative of the partial derivative of the cost function with respect to the public capital H.

$$B_h = -\frac{\partial C}{\partial H}$$

The shadow value is the cost-side equivalent of the marginal product. It reflects the reduction in total costs due to an incremental addition to the input stock, and thus the contribution of public infrastructure investment to the firms' efficiency and economic performance. The shadow value can be translated into an elasticity measure:

$$\varepsilon_h = B_h \frac{H}{C} = -\frac{\partial \ln C}{\partial \ln H}$$

From the view of firms, since the public infrastructure services are externally provided, $B_h > 0$ means the firms accrue benefits from increases in public infrastructure service. From a social perspective, however, infrastructure investment is clearly not free. Therefore, the social rate of return of public infrastructure capital must be measured by subtracting the so- called social user cost of public capital w_h from the shadow value B_h, i.e.,

$$r_h = B_h - w_h$$

However, constructing a social user cost is a very complicated issue. For more detailed discussion about the social user cost see Morrison and Schwartz (1996).

When empirically estimating the effects of public capital, a flexible translog cost function form is used by all researchers except Morrison and Schwarz (19960 and Seitz (1992) who instead use the Generalized Leontief cost function. This translog function is usually jointly estimated with cost share equations by the Zellner SUR method (Seemly Unrelated Regression), imposing theory-based constraints. In the case of using panel data, fixed effects models should be specified.

There are relatively few studies on the topic of the effects of public infrastructure investment using cost function approach. Post-1989 studies include Conrad and Seizt (1992), Seitz (1992), Shah (1992), Lynde and Richmond (1992, 1993), Nadiri and Manuneas (1994, 1996), Morrison and Schwartz (1996), and Khanam (1999) etc. Almost all studies focus on individual industry level, particularly the manufacturing industry. Interestingly, unlike the ones using the production function approach, the studies using the cost function approach have largely been consistent in reaching a conclusion that the public infrastructure investment has significant effects on reducing the cost of production in the private sector.

A study undertaken by Keeler and Ying (1988) before 1989 focuses on the benefits of Federal-aid highway infrastructure investments on costs in the U.S. road freight transport industry. Using data for nine regions from 1950 to 1973, they find highway infrastructure capital investments have significantly improved productivity in the trucking industry. The benefits of highway investments in truck cost savings alone are quite substantial, covering almost one third of the capital costs of the Federal-aid highway system between 1950-1973.

Morrison and Schwartz (1996) use a Generalized Leontief variable cost function to examine the role of infrastructure in determining the state level manufacturing industry's performance. The measure of public capital here includes highways, water, and sewer capital. The estimation is carried out by region with a fixed effects model, using annual data on the prices and quantities of output and inputs in the manufacturing sectors of 48 contiguous states for 1970 through 1987. The results show that shadow value exceeds zero for all states and time periods, indicating a positive marginal product of infrastructure capital for firms. It does, however, tend to be lower and have a smaller upward time trend than that of private capital. This suggests a higher return to private capital and a decline in the relative value of public to private capital over time in manufacturing industries. The shadow value measures suggest that a $1 investment infrastructure results in about a $0.16 cost saving in most regions for one year. Whether the social rate of return is positive or negative, however, is subject to which social user cost is used.

Nadiri and Mamuneas (1994) examine the effects of public infrastructure and R & D on the cost structure and productivity performance of twelve two-digit U.S. manufacturing industries for the period 1956-1986. They use the translog function with fixed industry effects. The results suggest that there are significant productive effects but vary across industries. They calculate that the social rate of return to public capital (based on the estimated marginal benefits and constructed social user cost) is about 7 percent. This is a slightly lower than the return to private capital which is 9 percent. Positive shadow values of public infrastructure capital are also found in the studies of Conrad and Seitz (1992) for Germany, Lynde and Richmond (1992) for the U.S. nonfinancial sector, Lynde and Richmond (1993) for the U.K., and Shah (1992) for Mexico.

Nadiri and Mamuneas (1996) offer a more comprehensive study on the linkage between highway capital and productivity growth using the cost function approach. This study estimates a model which encompasses both demand and supply factors that may influence industry and total economy productivity growth and uses data on 35 industries that covers the entire U.S. economy for the period 1950-1989. They examine the possibility of spurious correlation by estimating a model in first difference form. A flexible translog function form is used to allow interaction between highway capital and private sector output and inputs. No a priori restrictions, such as constant returns to scale are imposed on the parameters of the cost function. The issue of simultaneity is addressed by estimating the model using appropriate economic estimation techniques. Extensive hypothesis testing is also carried out to test the specification of the model and the stability of its results. Their analysis suggests that highway capital stock has contributed to the expansion of the productive capacity of the economy.

Nadiri and Mamuneas (1996) have estimated the effect of highway capital on the productivity growth at both aggregate economy level and individual industry level. At industry level, for each industry, cost and demand functions are estimated separately and the parameter estimates of model are used to decompose Total Factor Productivity (TFP) growth. The results show that the magnitudes of elasticity of cost with respect to highway capital vary among the industries. The cost elasticities in manufacturing industries range from –0.146 to –0.220 while in the non-manufacturing industries they range from 0.02 to 0.06. The marginal benefits (shadow values) in real terms appear to increase from 1950 to 1969 but decrease from 1970 to 1989 in each industry. All manufacturing industries have positive marginal benefits, the amount ranging from 0.002 to 0.029. However, according to the model, highway investments appear to have a negative impact on service industries in general. Particularly, a counter-intuitive result is that highway capital does not have positive impact on the transportation sector itself. Highway investment even raises costs in this industry. This also contrasts with the results of Keeler and Ying (1988) who use the same cost function approach, and of Fernald (1999), a production function based analysis.

To calculate the contribution of highway capital stock to the total productivity of the aggregate economy, Nadiri and Mamuneas sum the industry level data to the national level and then re-estimate the cost and demand equations. The aggregate cost elasticity is about 0.044. The output elasticity of highway capital averages 0.051 for the period as a whole. In particular, the output elasticity of private sector capital, which is 0.20, is clearly larger than the output elasticity of highway capital. The result indicates that a one percent change in private capital stock contributes almost four times as much to economic output as a one percent change in highway capital stock to growth of output of the economy.

The social rate of return on total highway capital was very high during the 1950’s and 1960’s At about 35% a year, it was much higher than the return on private capital, which averaged about 14% a year in this period. It has declined continuously since the late 1960s, however, and in 1989 it is barely above the level of the long-term interest rate. The estimated average rate of return for the period of 1950-1989 is 28 percent.

Nevertheless, as mentioned before, it is strongly arguable whether or not the cost function approach is appropriate at the aggregate economy level.

STUDIES IN THE CANADIAN CONTEXT

The studies discussed above are predominantly use data from the United States. However, there are also some studies concentrating on Canadian data using both production function and cost function approaches. These studies include Lynch (1994), Wylie (1995), Khanam (1996, 1999), and Waters (1999). As those on the U.S., the studies on Canada have mixed results and conclusions, due largely to econometric specifications.

Lynch (1994) estimates the effect of government capital stock in transportation (not just highways) on Gross Domestic Product or GDP for Canada and BC, respectively, using a Cobb-Douglas production function. The data are aggregate time series from 1966 to 1992. The other independent variables are effective private capital (adjusted by a utilization rate), government capital stock in areas other than transportation, and employment. In the BC model, government transportation capital is two year lagged and other government capital is one year lagged. The estimation is done only in first difference form rather than levels. This is to avoid spurious correlation problems but it runs the risk of focusing on short run relationships.

The elasticity of output to transportation capital is 0.0784 and 0.0226 in Canada and BC, respectively. The t-ratios are 1.865 and 1.046 respectively. This implies that both are insignificant. However, Lynch uses the critical values of a one-tailed test and concludes that the former one is significant at a 95% confidence level. But in such case a two-tailed critical value should be used. The insignificance of the coefficients (using two-tailed) is consistent to the U.S. studies that are justified by ‘first difference’. The elasticity of output with respect to other government capital is very high and significant. One unusual result is the coefficient for labour which is only 0.12066 in the Canadian model and highly insignificant. In the BC model, it is 0.34439, still not high.

Wylie (1995) specifies two models to examine the effect of infrastructure on output and labour productivity in the Canadian goods-producing sector, i.e., excluding both public and private services. He uses a translog production function together with a labour share equation to estimate the link with total output, and a Cobb-Douglas production function to relate to labour productivity. The data is aggregate time series from 1946 to 1991. The independent variables for the output (translog) model are labour, direct capital stock in the goods-producing sector, and the stock of infrastructure capital provided by the service sector. The infrastructure capital is further broken-down into core, service and public infrastructure in the productivity model. A time trend variable is introduced to the models.

Wylie argues that the appropriate specification is as a level rather than as a rate of change form, i.e., first difference. The flow of goods output over a period of time depends on the stock of infrastructure available to the goods-sector, as well as the stock of the sector's own capital, and the flow of direct labour services to it.

In the translog output model, infrastructure (including both public and private) is found to have a positive and significant effect on the output and the coefficient (0.2477) is greater than that of direct private capital. The role of public infrastructure is specified here. Though the coefficient of private capital is positive (0.2126) but not significant. A Zellner efficient estimator is used for this Seemingly Unrelated Regression (SUR) equation system.

A Cobb-Douglas production function model is specified to examine the effect of public infrastructure on labour productivity in the goods-sector in Canada. A coefficient of 0.517 for infrastructure (combined) is found significant, and higher than that for private capital which is 0.308. The coefficients for public infrastructure range from 0.407 to 0.436 but private infrastructure capital has a negative effect although it is insignificant. These are OLS results and Wylie notes that the results from AR (1) specification are no different so only the OLS results are reported. However, the DW values are quite low, between 0.508 and 1.109, indicating AR (1) results would be more appropriate to report. Not surprisingly, his results confirm Aschauer (1989a) and Munnell (1990a) who use the same aggregate time series methodology.

The major issue here is the measure of infrastructure capital. He defines total infrastructure capital as all capital stock in all service-producing sectors which include both private sector and public sector. This is further dividend into core, service and public infrastructure. Notice here that the “core” infrastructure is in fact capital stock in transportation, storage, communication and electric power industries. These are largely owned by the private sector and generally do not include highways. Public infrastructure which consists of government capital and other public capital, is close to the public capital we usually talk about. In his regressions, Wylie does not include all components of infrastructure into the estimation, i.e., there are always some components are omitted in the equations. This may result in biased estimates.

Using an almost identical approach, Khanam (1999) examines the effects of more clearly defined public infrastructure capital - highway capital on the labour productivity using both Cobb-Douglas and translog functions. The results are not much different. For example, the elasticity of output with respect to highway capital is 0.47 (and significant) in a no constraint Cobb-Douglas function equation.

One major research on public infrastructure and output in Canada using production function approach is that of Khanam (1996). She investigates the link between highway capital and economic output for the “goods producing sector” of the economy. She estimates Cobb-Douglas as well as translog production functions using 10 provincial data sets over 1961-1994. Many necessary econometric problems have been specified and tested. For instance, fixed time effect, and both fixed time and fixed province effects are incorporated into the models. Also, the models are re-estimated by first-differencing to test the spurious correlation.

Her main results from the panel data set show that the linkage is much smaller and weaker than that in the aggregate time series studies in Wylie (1995) and Khanam (1999). For her Cobb-Douglas function results, the elasticities range from 0.09 - 0.17, much smaller than those reported by the two studies above. A significant relationship between highway capital and provincial goods-producing sector output is reported when the model is only corrected for autocorrelation and heteroscedasticity. That is, a simpler regression model probably would give rise to seemingly stronger results but it would be erroneous because of the correlation of regression residuals from one year to the next. She also reports the results incorporating ‘dummy’ variables for time, i.e., ‘fixed time effects’. The elasticity is about 0.10 but not significant. The regression coefficient incorporating both time-specific and province-specific effects is only significant at a 10% level. The estimated elasticities in the fixed effect model with first difference, however, are simply insignificant. Although she reports a very high and significantly direct impact of highway capital on the economic output (the coefficient is 0.36) in the translog function, the second orders seem unnecessary since none is statistically significant.

Khanam (1996) only includes highway capital in the regressions, i.e., the other public infrastructure capital is excluded. This runs the risk of an omitted variable bias. She has also only examined the impact on the goods-producing sector. In this paper, she does not report the results of the fixed province effect model which is very important in studies using panel data.

A more complete study by production function approach has been done by Waters (1999). Econometric specifications are quite similar to Khanam (1996), e.g. fixing time and province effects, and first differencing. Further more, the model allows for contemporaneous cross-section correlation, i.e., provinces are not independent from one another. He uses Cobb-Douglas and translog functions to examine the effect of highway capital on the overall economy for the 10 Canadian provinces over 1961-1994, in addition to the goods-producing sector. Moreover, the other public capital variable which is omitted in Khanam (1996) is included in the estimation. The estimates show there is generally no significant linkage between the highway capital and the output, either of the overall economy or of goods-producing sector. In many case the signs are even negative. These are consistent to the U.S. studies (Eisner, 1991; Evans and Karras, 1994; Holtz-Eakin,1994) which use the similar econometric models. The results are also very sensitive to the econometric formulation of the regressions. The "other" public capital has always has a significantly positive output elasticity. But the causality test suggests that the other capital is more likely influenced by the output but not the other public capital impacts output.

With regards to the studies using cost function approach, there is only one attempt (Khanam, 1999) using data for Canada. This is an extension of her work of 1996 using the production function approach. The methodology follows those in the U.S. such as Morrison and Schwartz (1996) and Nadiri and Mamuneas (1994). She estimates a translog cost function to examine the cost saving impact of highway capital in the goods-producing sector for the period of 1961-1994. The results indicate that highway capital services reduce costs in the sector. The cost elasticities range from 0.07 to 0.22, implying large cost-saving benefits of additional units of highway infrastructure capital.

SUMMARY AND POLICY IMPLICATIONS

The 1950s and 1960s witnessed a dramatic increase in public infrastructure investment in Canada and the United States, particularly in highway infrastructure which is the major component of the public capital. However, a sharp fall in infrastructure investments occurred in the early 1970s and again in the early 1980s. These are the times that the economy performed poorly and productivity declined sharply. A possible link between infrastructure investment and economic performance was initially investigated by Aschauer and extended by Munnell, using aggregate time series data. However, these estimates are likely to have overstated the magnitude of the impact of public infrastructure investment on private sector output and productivity growth. It also does not make sense for public capital investment to have a substantially greater impact on private sector output than private capital investment.

Subsequent studies based on pooled time series and across-section data indicate a smaller and weaker contribution of public infrastructure investments and that the composition of infrastructure capital matters; some type of infrastructure (e.g. core infrastructure including highway, water and sewer system etc) may have a greater effect than others.

There are serious problems in these studies using both time series data and panel data in production function approach. Spurious correlation (non-stationarity) easily results in significant and substantial coefficients between the infrastructure capital and economic output. Trying to remove non-stationarity by first-differencing then runs the danger of focusing on the short relationship between these two variables, which is not the primary purpose of the studies. There is also no clear the direction of causation. Does the estimate suggest that economic growth is caused by infrastructure investment or a region with larger output or when a fast growing economy can afford to build more in infrastructure capital? Our review shows that the estimated results are largely dependent upon the econometric formulation. Simpler econometric specifications always have large estimates and they are statistically significant. A sophisticated regression then makes such estimates much smaller and weaker.

Cost function approach seems better suited to this analysis as it has many conceptual and econometric advantages over the production function approach. Interestingly, there have been consistent conclusions on the relationship between public infrastructure capital and productivity growth in the cost function based analysis. The evidence from this approach suggests that infrastructure investments contribute significantly to growth in output, reductions in cost and increases in profitability although the contribution is much smaller but may be more reasonable than what some production function based studies reported. Such contributions in most studies are also smaller than that of private capital. However, this evidence is largely based on manufacturing industries. When an attempt is made to extend it to the overall economy, its theoretical foundation is debatable.

The results obtained by the studies using data for Canada show almost the same pattern to those in the U.S. Aggregate time series studies report elasticity of productivity with respect to the public capital or highway capital at about 0.40. Adjustment by first difference then shows it has been reduced to barely 0.08 and statistically very weak significance. Panel data studies with more sophisticated econometric formulations do not even support the argument that infrastructure capital significantly contribute to economic growth. The cost function approach, however, shows such relationships do exist, though the magnitude is much smaller (the cost elasticity ranges from 0.07-0.22).

Turning to the policy implications, the controversial evidences from the studies we reviewed leave room open for discussion. Cost function approach studies evidence that highway infrastructure has substantial payoffs. Does this imply that the infrastructure is undersupplied and higher levels of investment are warranted? These studies also indicate, however, that the return to private capital exceeds that to public capital. In other words, as Gillen (1996) argues, the fact there is a positive return to public capital does not make it necessarily an optimal choice.

If the infrastructure investment has very weak or no contribution to the productivity growth as reported in many pooled time series and cross-section studies with more sophisticated econometric formulations, does it suggest that the provision of road networks, bridges, water supply systems etc does not play any roles in economic growth? This is obviously a departure of common sense. One possibility is that output measure (e.g. GNP) does not include nonmarket values, and a large part of infrastructure contributions provide such kinds of nonmarket benefits to the society. As Blinder (1991) has observed, “If my car and my back absorb fewer shocks from potholes, I am surely better-off; but the GNP may even decline as a result of fewer car repairs and doctor's bills."

It is argued (Fox, 1990) that capital stock may not be an accurate measure of infrastructure services. This implies that the results obtained by the studies using infrastructure capital stock as a proxy of infrastructure services do not necessarily reflect true effects. Policy thus can be directed to the range of management such as the efficient use, design, and management of transportation infrastructure that could significantly increase the flow of infrastructure services without necessarily increasing the stock of infrastructure.

In conclusion, two sets of policies could be simultaneously given attention. One looks specifically at the quality of services and the potential utilization of existing transportation infrastructure. The other elaborates on the future need for transportation infrastructure capital to potential growth of the economy, and the spatial distribution of economic activities.

Notice that, however, it is not the intention of the macro studies to provide guidance for any specific transportation infrastructure investment decisions. These require microeconomic tools, such as social cost-benefit analysis.

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