Transportation (2006) 33:537–551
DOI 10.1007/s11116-006-8472-2

RESEARCH ARTICLE

Empirical analysis of transportation investment and economic development at state, county and municipality levels

Joseph Berechman · Dilruba Ozmen · Kaan Ozbay

Received: 25 March 2005 / Accepted: 3 January 2006 /
Published online: 15 September 2006

Abstract Numerous studies have found positive correlation between transportation infrastructure investment and economic development. Basically these studies use a conventional production function model augmented by a public capital input, mainly highways, rail and other transportation facilities. While the range of the measured economic growth effects varies widely among studies, the positive elasticity between transportation investment and economic development is now commonly accepted. Still a major puzzling issue is that the magnitude of the measured effect seems to decline significantly as the econometric model is further refined, mainly with regard to space and time lags. That is, the use of national or state data produces elasticity results, which are much larger than when using county or municipality data. Similarly, when we introduce into the econometric model a lag between the times when the transportation investments are made and when the economic benefits transpire, the measured elasticities decline with the size of the lag. Thus, the main objective of this paper is to investigate these issues analytically and empirically and provide a plausible explanation. We do so by using alternative econometric models, applying them to a database, which is composed of longitudinal state, county and municipality observations from 1990 to 2000. The key result is that transportation investments produce strong spillover effects relative to space and time. Unless these factors are properly accounted for many reported empirical results are likely to be overly biased, with important policy implications.

Keywords highway investment · private capital · public capital · spillover effects · time lags

J. Berechman (✉)
Sauder School of Business, University of British Columbia, Vancouver, Canada
e-mail: joseph.berechman@sauder.ubc.ca

D. Ozmen
Hofstra University, Engineering Department, Hempstead, NY, 11549, USA

K. Ozbay
Rutgers, The State University of New Jersey, Piscataway, USA

Introduction

Over the last decade numerous studies have been conducted on the impact of transportation infrastructure development on economic growth. The major objectives of these studies have been to estimate the returns of transportation investments by type (e.g., highway or public transit) and by geographical level (e.g., national, state). The most common approach is to develop a production function type model in which transportation infrastructure is treated as a public capital, which like other inputs (mainly private capital and labor), impacts output. Longitudinal and pooled databases have been used to estimate output elasticities as well as labor, private and public capital productivity.

While the estimated results vary considerably as explained in detail in the next section, they nonetheless have established a positive association between transportation investment and economic growth. Yet, several basic questions remain unsolved. First, what is the nature of the causality between transportation investment and economic growth? Does the former variable indeed affect the latter, as all of these studies implicitly assume, or that highly developed economies can afford greater transportation capital expenditures so that the causality, in fact, should be reversed? The second puzzling issue is that systematical analysis done at one geographical level (e.g., state) will produce estimates, which are significantly different than those produced for another (e.g., county). Put alternatively, it seems that when we sharpen the econometrics by zooming on smaller scale areas, transportation capital output elasticity diminishes. Third, does there exist a lag between the time when the actual transportation investment is being made and the time when the economic benefits transpire? If so, what is the nature of this lag in terms of its length and its relationships with the geographical level of the analysis? A related question is what are the underlying forces that produce these results? We hypothesize that spatial spillover effects, especially at smaller geographical levels, can largely explain these results. To corroborate this hypothesis we formulate a production function model with variables that reflect transportation capital accumulation at adjacent geographical units. We then estimate the model using state, county and municipality data. Finally, we ask at a given spatial level, does the impact of highway capital on output vary across sub-regions and if so what is the pattern of such variations?

In this paper we focus on the second and third issues, namely the relationships between the geographical scale of analysis and the output elasticity of transport investment and the impact of the time lags on these results. However, we also briefly explore regional variations in the effect of highway capital on output at a particular geographical level.

The paper is designed as follows. In the next section we present the results from existing literature. Then, we present the database used for the empirical analysis. In the next section we introduce three model types that are used for the estimation of the relevant parameters. The estimated parameters are presented and discussed subsequently. Next, results of model validation tests are presented. The paper ends with several policy conclusions that ensue from the estimated results.

Results from the literature

Numerous empirical studies have been carried out since the seminal work of Aschauer (1989) on the relationships between transportation capital investment and economic development. The key policy results from these studies pertain to output elasticity with respect to transportation capital. Table 1 below reports results from a number of studies on

Table 1 Output elasticity results from various studies

Study	Country	Level of analysis	Data	Functional form	Infrastructure considered	Output elasticity
Eberts (1986)	U.S.	State	Time series	C–D[a], Translog	Public capital[b]	0.03
Costa et al. (1987)	U.S.	State	Cross-section	C–D, Translog	Public capital	0.20
Aschauer (1989)	U.S.	National	Time series	C–D	Public capital	0.39–0.56
Munnell (1990)	U.S.	National	Time series	C–D, Translog	Public capital	0.33[c]
Munnell (1990)	U.S.	State	Pooled	C–D, Translog	Highway capital[d]	0.06
Munnell (1990)	U.S.	State	Pooled	C–D, Translog	Public capital	0.15
Duffy-Deno and Eberts (1991)	U.S.	Metropolitan Area	Pooled	C–D, Translog	Public capital	0.08
Moomaw and Williams (1991)	U.S.	State	Pooled	Translog	Highway capital	0.25
Lynde and Richmond (1992)	U.S.	National	Time series	Translog	Public capital	0.20
Garcia-Mila and McGuire (1992)	U.S.	State	Pooled	C–D	Highway capital[e]	0.04
Garcia-Mila and McGuire (1992)	U.S.	State	Pooled	C–D	Highway capital	0.13
Garcia-Mila and McGuire (1992)	U.S.	State	Pooled	C–D	Highway capital	0.12
Ozbay et al. (2003)	U.S.	County	Pooled	Multiple Regression	Highway investment (in terms of accessibility)	0.09
Ozbay et al. (2006)	U.S.	County	Time series	C–D, Translog	Highway capital	0.21
Waters (2004)	Canada	Province	Time series	C–D, Translog	Highway capital	0.08

[a] C–D: Cobb–Douglas

[b] Governmental Finances, a US Bureau of Census publication, defines capital outlay as direct expenditure for the construction of buildings, roads, and other improvements, including additions, replacements, and major alterations to fixed works, and structures, whether contracted privately or built directly by the government

[c] Labor productivity elasticity

[d] As well as sewer, water and others

[e] As well as education

the subject. As evident from this table, the output elasticity results vary widely ranging from a very high 0.39–0.56, (Aschauer 1989) or 0.33, (Munnel 1990) to a very low 0.04, (Garcia-Mila and McGuire 1992) or 0.08 (Waters 2004). This wide diversity of output elasticity estimates is probably the result of differences between studies relative to spatial level of analysis, definition of capital stock as well as underlying models.

Most of the previous studies have used a production function model with a similar structure. Eakin (1994) for instance, has applied a production function to state level data set consisting of output, labor, private capital and state and local government capital. The study has concluded that the elasticity of private output with respect to public sector capital is quite large (0.23). Munnell (1992) examined spillover effects by hypothesizing that highway public capital creates positive cross-state spillovers. She argued that this could occur when infrastructure investments in one state benefit people in others. Eakin and Schwartz (1995) have studied similar effects and measured the indirect effect of highway capital investment on neighboring states. However, they have rejected the hypothesis that highway capital has positive output spillovers. In fact, in some of their specifications, the spillover parameter was significantly negative. Yet, theoretically indirect effect from highway capital investment is the net result of the two offsetting effects. These are: a relocation of economic activity (e.g., Forkenbrock and Foster 1990), and the spillover effect (Munnell 1992). Boarnet (1996) has examined how highway investments redistribute economic activity, by dividing the economic impacts of transportation infrastructure into a direct effect (impact near a street or a highway) and indirect effect (any impact that occurs at locations more distant from the highway corridor). He concluded that the direct and indirect effects were equal in magnitude with opposing signs.

On the question of the relationships between public capital investment and private economic activity, Munnell (1990) has estimated a model in which public capital affects output, employment growth, and private investment at the state and regional levels. The dependent variable was state product, while the independent variables were level of technology, private capital stock, labor and the stock of public capital. The regression results confirmed, at the state level, that public capital has a significant positive impact on the level of output, disregarding possible spillover effects. The elasticity for the private capital in the equation was found to be 0.31, whereas that of public capital was 0.15, both highly significant. Haughwout (2000) proposed a spatial general equilibrium model of an economy with non-traded, localized public goods like infrastructure. The results show that infrastructure provides significant productivity and consumption benefits to both sectors firms and households. The elasticity for the public capital was estimated to be non-negative, but small.

The database

The database used in this study is composed of state, county and municipality data. These are:

State Level (48 states. All values are in millions of year 2000 dollars unless otherwise stated)

H: End-of-year highway capital stock in each state (Source: Munnell 1992)
K: End-of-year non-residential private capital stock (Source: Munnell 1992)
NH: End-of-year highway capital stock in neighboring areas
Q: Gross State Product (Source: NJ Department of Labor)

L: Employment (number of jobs) (Source: Real Estate Center, Texas A&M University)
State *U*: State unemployment rate (%), based on national unemployment (Source: Real Estate Center, Texas A&M University)

County Level (18 counties in New York/New Jersey Metropolitan area. All values are in millions of year 2000 dollars unless otherwise stated).

H: End-of-year highway capital stock[1] in each county (Source: Eqn.1 in Ozbay et al. 2006)
K: End-of-year non-residential private capital stock (Source: Munnell 1992). States' values were apportioned among counties based on personal income
NH: End-of-year highway capital stock in neighboring areas
Q: Gross County Product (Source: NJ Department of Labor, State values were apportioned to counties based on personal income)
L: Employment (number of jobs) (Source: Real Estate Center, Texas A&M University)
County *U*: Based on state unemployment rate (%) (Source: Real Estate Center, Texas A&M University)

Municipality Level (389 municipalities in NY/NJ Metropolitan area. All values are in millions of year 2000 dollars unless otherwise stated)

H: End-of-year highway capital stock in each municipality (County values were apportioned among municipalities based on personal income)
K: End-of-year non-residential private capital stock (County values were apportioned among municipalities based on personal income)
NH: End-of-year highway capital stock in neighboring areas
Q: Gross Municipality Product (County values were apportioned among municipalities based on personal income)
L: Employment (number of jobs) (Source: Real Estate Center, Texas A&M University)
Municipal *U*: Based on county unemployment rate (%) (Source: Real Estate Center, Texas A&M University)

Formulation of models

In this study we have used three types of models: a basic production function model, a time lag model and a spatial spillover model. Each of these is estimated for the three levels of analysis: state, county and municipality. We begin by introducing the basic production function model, on which basis the other two model types were formulated.

$$\log(Q_{c,t}) = \beta_0 + \beta_1 U_{c,t} + \beta_2 \log(L_{c,t}) + \beta_3 \log(K_{c,t}) + \beta_4 \log(H_{c,t}) + \varepsilon_{c,t} \quad (1)$$

where: ε: Error term

β_i (i=1,. . .,4): Parameters to be estimated
U: Larger scale unemployment rate (e.g. state level rates for county analysis)
c: Index of state, county or municipality

[1] As used in this study, public capital is the dollar amount (in millions) of the summation of ''Expenditure of Federal Funds Administered by The Federal Highway Administration'' and ''State Highway Agency Capital Outlay and Maintenance.'' Only the sectors pertaining to highways are included. More information can be found at http://www.fhwa.dot.gov/policy/ohim/hs03/hf.htm.

t: Year index (1990–2000)

This model is similar to those used in the germane literature save for the addition of an unemployment explanatory variable, which is introduced into the model as an instrumental variable to account for the economic activity dynamics, which take place at a scale larger than the present level of analysis.

In order to investigate possible lags between the time of the investment and the time of its impact on output the following model is estimated:

$$\log(Q_{c,t}) = \beta_0 + \beta_1 U_{c,t} + \beta_2 \log(L_{c,t}) + \beta_3 \log(K_{c,t}) + \beta_4 \log(H_{c,t-n}) + \varepsilon_{c,t} \tag{2}$$

where: n=1,2,...,5 years.

Next, we developed a spillover model that takes into account the effects of highway investment on areas, which neighbor the investment's location.

$$\log(Q_{c,t}) = \beta_0 + \beta_1 U_{c,t} + \beta_2 \log(L_{c,t}) + \beta_3 \log(K_{c,t}) + \beta_4 \log(H_{c,t}) + \beta_5 \log(\mathrm{NH}_{c,t}) + \varepsilon_{c,t} \tag{3}$$

Finally, we calculated the output elasticity with respect to highway capital, β_4 in Eq. 1:

$$\beta_4 = \frac{\frac{\Delta Q}{Q}}{\frac{\Delta H}{H}} \tag{4}$$

By rearranging and substituting the values for Q and H(for given years) we obtain the marginal output of highway capital, $\frac{\Delta Q}{\Delta H}$, i.e.,

$$\frac{\Delta Q}{\Delta H} = \beta_4 * \frac{Q}{H} \tag{5}$$

This value is the percent change in Q (gross state, county or municipality product) in response to a 1% change in highway capital (H).

Estimation results

In this section we present the key results from the time series analysis estimation of the three models (Equations 1–3), relative to the three geographical levels of analysis: state, county and municipality. In particular, we focus on the output elasticity from highway capital development, which as was shown in Table 1, ranges from a very high to a very low elasticity.

Results from the estimation of the basic model

The results from the basic model are summarized in Table 2. Clearly these results lend further evidence to Munnell's conclusion that the estimated impact of highway capital weakens as the geographic study area gets smaller (Munnell 1992). As explained below this phenomenon is due to pronounced spillover effects.

Table 2 Estimation Results from the Basic Model

	Intercept (β_0)	U (β_1)	log L (β_2)	log K (β_3)	log H (β_4)	R-Sq	Number of Observations[a]	Durbin–Watson
State	−3.19	−0.046	0.99	0.025	0.047	0.98	528	1.92
[t-statistic]	[−33.3]	[−8.9]	[63.4]	[1.6]	[2.4]			
County	0.47	−0.06	0.079	0.925	0.045	0.98	198	1.98
[t-statistic]	[2.2]	[−9.9]	[1.8]	[16.7]	[3.8]			
Municipality	0.06	−0.035	0.205	0.818	−0.002	0.99	4279	1.94
[t-statistic]	[1.6]	[−37.9]	[18.5]	[78.8]	[−0.87]			

[a] Number of states, counties and municipalities multiplied by analysis period of 11 years

Estimates of output elasticity with respect to highway capital

In order to illustrate the computation of the marginal output of highway capital (Eq. 5), consider the case of the county level data. In 2000, total gross county product (Q) in the study area was $633,692 million and total county highway capital was $85,235 million. From Table 2, the coefficient for highway capital at the county level is 0.045. Substituting these values into Eq. 5 yields the Marginal Productivity of highway capital of 0.34. That is:

$$\frac{\Delta Q}{\Delta H} = 0.045 * \frac{633692}{85235} = 0.34$$

This figure indicates the percent change in gross county product (GCP) from a 1% change in highway capital. It implies that a $1 increase in highway capital leads to a long-term accumulated increase in GCP of 0.34 dollars. The direct elasticity is 0.045, which implies an increase of $4.5 in GCP in response to a $100 capital investment. Table 3 summarizes the output elasticity results for the state, county and municipality levels. Again, it is evident that output elasticity declines, as the geographic focus gets smaller.

Another way of interpreting the output elasticity is by computing the rate of return of capital investment at the three geographical levels. For example, for the 11 years (1990–2000), highway capital has an average rate of return of 7.6% for the county level (0.34 divided by 0.045). Figure 1 shows the rate of return of the highway capital as function of time for state, county and municipality levels.

As can be seen from this figure, for state and county levels the rate of return steadily increased during the entire period (1990–2000). At municipality level, however, a discernible variable trend is observed, which we have interpreted as indicating spillover effects at the level of analysis. Another result from Fig. 1 is that the average rate of return over the 11-year period is 7.18%, 5.09% and 4.33% for the state, county and municipality levels, respectively. These results further support our contention that the impact of highway capital on economic growth weakens as the geographic scale gets smaller.

Table 3 Output elasticity of highway capital

Level	Direct elasticity (β_4)	Output elasticity
State	0.047	0.37
County	0.045	0.34
Municipality	−0.002	−0.01

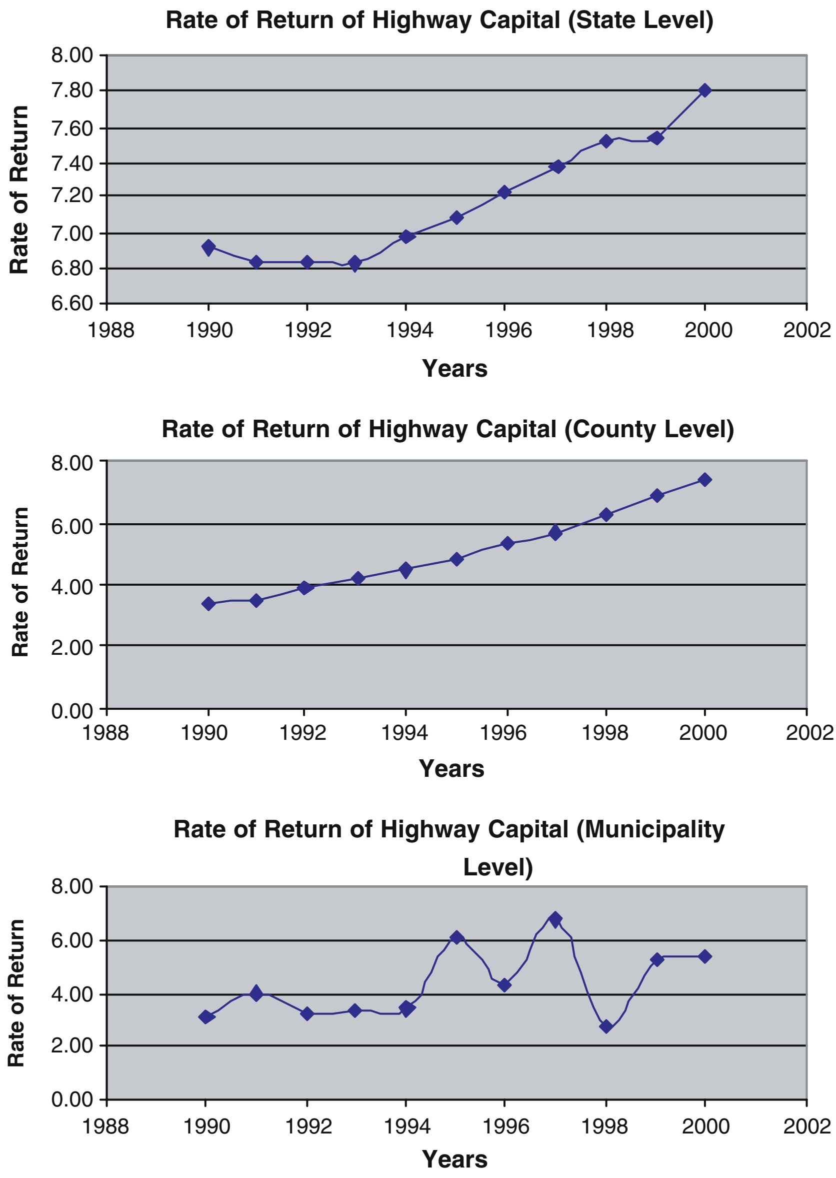

Fig. 1 Rate of return of highway capital (State, County, and Municipality)

Results from the estimation of the lag model

In the estimation of model (2) several time lags were tried (n=1,2,...,5 years). The most sensible and statistically significant results were obtained for 1-year lags. This is not surprising considering the fact that the economic cycles at all the three geographical levels demonstrate an increasing gross product over time, which in turn, are associated with shorter lagging effect of highway investments. The results of the model for the 1-year lag are given in Table 4.

Table 4 Estimation results from the Lag model (1-Year Lag)

	Intercept (β_0)	U (β_1)	log L (β_2)	log K (β_3)	log H (β_4)	*R*-Sq	No. of Obs.[a]	D–W
State	−3.18	−0.05	1	0.019	0.046	0.98	480	1.94
[*t*-statistic]	[−32.4]	[−9.1]	[61.6]	[1.2]	[2.3]			
County	0.6	−0.08	0.08	0.92	0.044	0.99	180	1.91
[*t*-statistic]	[3.9]	[−17.9]	[2.6]	[34.5]	[7.9]			
Municipality	−0.001	−0.04	0.24	0.8	−0.009	0.99	3890	1.97
[*t*-statistic]	[−0.01]	[−60.5]	[27.4]	[98.8]	[−5]			

[a] Number of states, counties and municipalities multiplied by analysis period of 10 years

It is evident from the results shown in this table that the inclusion of a lag variable slightly reduces the coefficient of highway capital for all three levels of analysis. One possible explanation is that highway capital stock accumulation over time is a function of the amount of highway investment made and is largely independent of time lags. As before the impact of highway capital diminishes, as the geographic level of analysis gets smaller.

Results from the estimation of the spillover model

The third set of results was obtained from estimating the spillover model. For a spillover effect to exist β_4 in Eq. 3 must be negative while β_5 positive (and statistically significant). The results shown in Table 5 indicate that there are no spillover effects at state and county levels (the β_4 are positive). The reason for this result could be due to the fact that most of the economic activity defined in the output variable, Q, is contained within the state and county but not in the municipality. The negative coefficient observed for the variable H at the municipality level indicates that the spillover effects are dominant at this level of analysis. This finding is consistent with the argument made by Boarnet (1995) that more spillovers are observed at geographic areas such as cities and municipalities than at states and regions.

Statistical tests for the validation and robustness of the estimated results

In order to validate the statistical significance of the results estimated from the three models, we performed several statistical tests aimed at testing possible model misspecification, heteroscedasticity, and the existence of time-related and spatial autocorrelation.

Since the database used in this study is composed of time series data, we tested for the existence of autocorrelation in order to validate the robustness of the regression results. Specifically, we tested for a systematic pattern in the error terms that indicate either attracting (positive) or repelling (negative) autocorrelation (Marsh 1999) by using the

Table 5 Estimation results from the Spillover model

	Intercept (β_0)	U (β_1)	log L (β_2)	log K (β_3)	log H (β_4)	log NH (β_5)	*R*-Sq	No. of Obs.[a]	D–W
State	−3.4	−0.05	1	0.028	0.035	0.021	0.98	528	1.94
[*t*-statistic]	[−27.1]	[−8.8]	[63.7]	[1.8]	[1.8]	[2.5]			
County	0.6	−0.065	0.045	0.94	0.042	0.022	0.99	198	1.91
[*t*-statistic]	[2.7]	[−10.2]	[1]	[24.5]	[4.3]	[2.2]			
Municipality	0.024	−0.04	0.21	0.81	−0.009	0.01	0.99	4279	1.97
[*t*-statistic]	[0.6]	[−39.2]	[19.4]	[77.6]	[−3.7]	[9.3]			

[a] Number of states, counties and municipalities multiplied by analysis period of 11 years

Durbin–Watson test statistic. The test compares the residual for time period t with the residual from time period ($t-1$) and develops a statistic that measures the significance of the correlation between these successive comparisons. Details of the test are in the Appendix. In addition, and as can be seen from the relevant columns of Tables 2, 4 and 5, the value of the test statistic for all models is very close to 2. Therefore, it can be concluded that there is no sign of autocorrelation problem in the models developed in this paper.

The spatial autocorrelation test is carried out in order to test for any systematic pattern in the spatial distribution of a variable. Positive or negative spatial autocorrelation indicate neighboring areas, which are more alike or unlike, respectively, whereas random patterns exhibit no spatial autocorrelation. Thus, the spatial autocorrelation test, tests the assumption of randomness (Lembo 2004). Here we have used the standard Moran's index (Moran's I), as an indicator of spatial autocorrelation. This index can be applied to zones or points with continuous variables associated with them. It compares the value of the variable at any one location with its values at all other locations. The test statistics are described in the Appendix. The results of the spatial autocorrelation analysis indicate that there is no significant spatial autocorrelation in these models. The Moran's indexes for the state, county and municipality levels analysis were 0.021, 0.057 and 0.0025, respectively. Furthermore, the statistical significance of this result was justified by the z-scores obtained by using Eq. A3 in the Appendix at 90% confidence interval. In addition, we have tested the models for possible misspecification and heteroscedasticity and were satisfied that neither of these possible complications were an issue.

Finally, we have tested for the robustness of the three models. To that end, we tested the predicted output results of the county level basic and lagged models (the results shown in Tables 2 and 4) on other geographical areas not included in our database, which include 8 counties in southern New Jersey. We used labor and capital stock data for these 8 counties between 1990 and 2000 and estimated their output using our models. We then compared these estimated results with the actual levels of output of these counties. Our estimation results were accurate with 7.9% error. For the county level lag models, our estimation results were accurate with 8.3% error. We judge these errors to indicate robustness, especially if these counties have different economic activity dynamics than the ones in the original database.

Further corroboration of results

Are the above results supported by theories, which predict the impact of transportation capital investment on regional economic growth? Hansen (1965) hypothesized that the potential effect of economic overhead capital (infrastructure capital) augmentation, varies across three broad regional categories. These are lagging, intermediate, and congested regions. Lagging regions are characterized by a low standard of living due to small-scale agriculture sector and/or stagnant or declining industries. These regions do not attract new firms and public infrastructure investment would have little impact on economic growth (Eberts 1990). Intermediate regions are characterized as having abundance of well-trained labor, cheap power, and raw materials. In such regions increased economic activity, resulting from infrastructure investment, would lead to marginal social benefits exceeding marginal social costs. Congested regions are characterized by very high concentrations of population, industrial and commercial activities, and public infrastructure. Any marginal social benefits that might result from further public capital investment would be outweighed by the marginal social costs of pollution and congestion stemming from increased economic activity.

In another study Kim and Lee (2002) investigated the relationship between public capital and technical efficiency. Their analysis is based on the proposition that public capital can affect actual output by enhancing technical efficiency, thereby reducing the gap between maximum potential output and actual output. Using panel data from U.S. state manufacturing industries during 1969–86, they concluded that technical efficiencies varied substantially both between states and between years; and variations in technical efficiency are significantly explained by variations in public-sector capital.

To corroborate our results we made use of Hansen's (1965) hypothesis. Accordingly we have used our state-level database in order to ascertain if there are systematic variations in the contribution of highway capital to output across regions in the U.S. and, if so, what is the pattern of these variations. Using the State's level of highway capital, employment and population we have categorized states as lagging regions, intermediate regions, and congested regions. We then estimated our basic model for these three region types. Table 6 summarizes the results from this analysis. Two important findings emerge from this table. First, the contribution of highway capital to output indeed varies across regions with differing characteristics. Second, our findings support Hansen's theory that in intermediate regions, the contribution of highway capital to state's output is more pronounced than in the congested regions. Thus, the direct elasticity for the intermediate regions was estimated as 0.35 while for the congested regions the estimated elasticity was 0.29. For the lagging regions it was estimated as −0.03.

Given these results we have, therefore, concluded that both the database and models used in this study indeed capture the relationships between transportation capital expansion and economic growth at the three geographical levels of analysis.

Conclusions

This paper asks the empirical question: what are the relationships between transportation capital development and economic activity at the state, county and municipality levels? To that end, we have developed and used three types of models. These are, first, a production function type model with output as the dependent variable and labor, private capital, public capital (transportation capital) and unemployment as independent variables. This model type was labeled as ''basic model''. The second model type is a lagged model in which 1–5 years time lags were introduced to test for possible delays in output response to additional transportation investment. The third model type is a spillover model whose objective is to test the hypotheses that highway investments made in one area have economic development impacts on neighboring areas and that these impacts become more

Table 6 Results from regional analysis

U.S. Regions	Highway capital (Millions)	Population (Millions)	Employment (Millions)	Direct elasticity of highway capital
Lagging[a]	$0–25,000	0–5	0–3	−0.033
Intermediate[b]	$25,000–50,000	5–10	3–5	0.351
Congested[c]	>$50,000	10–20	5–10	0.297

[a] 36 States fell into this group

[b] 6 States, (Florida, Kentucky, Louisiana, Michigan, New Jersey, and Virginia) fell into this group

[c] 6 States (California, Illinois, New York, Ohio, Pennsylvania, and Texas) fell into this group

pronounced as the geographical area gets smaller. We further carried out several statistical tests to validate the estimated results. In addition, we have studied the variations in the effect of highway capital on output across regions using our state level database.

Based on the empirical results reported in this paper the following key conclusions were drawn.

(a) Private and public capitals have positive and statistically significant impacts on output at the state, and county levels.
(b) The magnitude of the impact of public capital declines, as the geographical scale gets smaller due to more pronounced spillover effects.
(c) For state, county and municipality level, when various time lags are applied to highway capital, the coefficients associated with that variable are smaller compared with the non-lag case. We interpret these results as indicating that in New Jersey, where the accumulation of transportation capital stock is mainly a function of the amount of highway investments made, output responds immediately to capital investments, largely independent of time lags. Perhaps expectations from highway construction play a major role in this regard.
(d) Spillover effects onto neighboring areas surrounding the location where the highway investment was made tend to increase, as the geographical area of analysis gets smaller. That is, we can expect large output spillover effects at the municipal level from investments made in adjacent locals.
(e) The output elasticities with respect to public highway capital obtained in this study are 0.37, 0.34, and −0.01 for state, county and municipality levels, respectively. These estimates are in accord with the results obtained in other studies (see Table 1). Their decreasing magnitude again reflects the spillover effects noted above.
(f) The rate of return of highway capital over the years (1990-2000) displays a smoothly increasing pattern for state and county level analysis. For municipality level, however, a strong fluctuating trend is observed, again reflecting the spillover effects in the study area.
(g) Contribution of highway capital to output varies across regions with differing socioeconomic characteristics, which support theories advanced in the literature.

As a final note, it should be emphasized that the results presented in this paper are mostly appropriate for similar aggregate-level analysis (i.e., municipal, county or state) rather than for corridor-specific analysis. However, to the degree that the empirical results obtained for New Jersey relative to the spillover effects are generic, what can be said of the economic development impacts at the corridor level of specific transportation investment projects? Should the analysis of these impacts be confined to the area where the investment is made or be expanded to the entire metropolitan area? These questions are subjects for further research.

Acknowledgments The revised paper is largely based on very useful comments received from three anonymous referees, for which we wish to thank them. As usual, the remaining errors are ours.

Appendix: Autocorrelation tests

The Durbin–Watson test for first order autocorrelation

The formula for the D–W statistic is given in Eq. A1:

$$d = \frac{\sum_{t=2}^{n} (e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2} \qquad (A1)$$

where:

d: Durbin–Watson statistic
e: Residual
t:Time period counter

D–W statistic is used to test for the presence of both positive and negative correlation in the residuals. The statistic has a range of from 0 to 4, with a midpoint of 2. The null hypothesis (H_0) is that there is no significant correlation.

$H_0 : \rho = 0$
$H_1 : \rho \neq 0$

‘‘d’’ is approximately related to ‘‘ ρ’’ as $d \approx 2(1-\rho)$. When ρ=0, the D–W statistic is $d \approx 2$.

The Moran Test for spatial autocorrelation

$$I = \frac{N \sum_i \sum_j W_{i,j}(X_i - \bar{X})(X_j - \bar{X})}{(\sum_i \sum_j W_{i,j}) \sum_i (X_i - \bar{X})^2} \qquad (A2)$$

where:

N: Number of cases (in this paper, it’s 48 for state, 18 for county, and 389 for municipality level analysis)
X_i: Variable value at a particular location
X_j: Variable value at another location
X: Mean of the variable
W_{ij}: Weight applied to compare between locations i,j (1 if these locations share a border, 0 otherwise).

Similar to correlation coefficient, Moran’s index varies between −1.0 and + 1.0. When autocorrelation is high, the coefficient is high. A high I value indicates positive autocorrelation. The statistical significance of the calculated Moran’s indices can be determined using Eq. A3 (Anselin 2005).

$$Z(I) = \frac{I - E(I)}{S_{E(I)}} \qquad (A3)$$

where:

$Z(I)$: Z-score for standard normal distribution
I: Calculated Moran’s index

$E(I)$: Theoretical mean given by Eq. A4
$S_{E(I)}$: Theoretical standard deviation given by Eq. A5.

$$E(I) = -\frac{1}{N-1} \quad (A4)$$

$$S_{\mathrm{E(I)}} = \mathrm{SQRT}\left[\frac{N^2 \sum_{ij} w_{ij}^2 + 3\left(\sum_{ij} w_{ij}\right)^2 - N \sum_i \left(\sum_j w_{ij}\right)^2}{(N^2-1)\left(\sum_{ij} w_{ij}\right)^2}\right] \quad (A5)$$

References

Anselin, L.: Spatial Regression Analysis in RA Workbook. Center for Spatially Integrated Social Science. University of Illinois, Urbana-Champaign (2005)

Aschauer, A.D.: Is public expenditure productive? J. Monetary Econ. **23**(2), 177–200 (1989)

Boarnet, M.G.: Transportation infrastructure, economic productivity, and geographic scale growth versus spatial redistribution Working Paper No. 255, The Transportation Center, University of California, Berkeley, CA (1995)

Boarnet, M.G.: The direct and indirect economic effects of transportation infrastructure Working Paper No. 340, The Transportation Center, University of California, Berkeley, CA (1996)

Costa, J.S., Ellson R.W., Martin R.C.: Public capital, regional output, and development: some empirical evidence. J. Regional Sci. 419–437 (1987)

Duffy-Deno, K.T., Eberts, R.W.: Public infrastructure and regional economic development: a simultaneous equations approach. J. Urban Econ. **30**(3), 329–343 (1991)

Eakin, D.H.: Public sector capital and productivity puzzle. The Rev. Econ. Stat. **76**(1), 12–21 (1994)

Eakin, D.H., Schwartz, A.E.: Spatial productivity spillovers from public infrastructure: evidence from state highways. International Tax and Public Finance (1995)

Eberts, R.W.: Estimating the contribution of urban public infrastructure to regional economic growth. Federal Reserve Bank of Cleveland, Working Paper No. 8610, December (1986)

Eberts, R.W.: Public infrastructure and regional economic development. Economic Review Federal Reserve Bank of Cleveland Quarter **1**, **26**(1):15–27 (1990)

''FHWA highway statistics series.'' <http://www.fhwa.dot.gov/ohim/ohimstat.htm>

Forkenbrock, D.J., Foster, N.S.J.: Economic benefits of a corridor highway investment. Transport. Res. **24A**(4), 303–312 (1990)

Garcia-Milla, T., McGuire T.J.: The contribution of publicly provided inputs to States' economies. Regional Sci. Urban Econ. **22**, 229–241 (1992)

Hansen, N.M.: Unbalanced growth and regional development. Western Econ. J. **4**, 3–14 (1965)

Haughwout, A.F.: Public infrastructure investments, productivity and welfare in fixed geographic areas. Federal Reserve Bank of New York, Staff Report 104, May (2000)

Kim, S., Lee, Y.H.: Public sector capital and the production efficiency of U.S. regional manufacturing industries. Jpn. Econ. Rev. **53**(4), 466–482 (2002)

Lembo, A.J. Jr.: Spatial Modeling and Analysis Lecture notes, Cornell University, Department of Crop and Soil Sciences (2004)

Lynde, C., Richmond J.: The role of public capital in production. Rev. Econ. Stat. **74**, 37–44 (1992)

Marsh, L.: The nature of autocorrelation. SHAZAM Econometrics Software Online Support. <http://shazam.econ.ubc.ca> (1999)

Moomaw, R.L., Willians, M.: Total factor productivity growth in manufacturing: further evidence from the States. J. Regional Sci. **31**(1), 17–34 (1991)

Munnell, A.H.: How does public infrastructure affect regional economic performance. New Engl. Econ. Rev. September–October, 11–32 (1990)

Munnell, A.H.: Policy watch: infrastructure investment and economic growth. J. Econ. Perspectives **6**(4), 189–198 (1992)

Ozbay K., Ozmen D., Berechman J.: Empirical analysis of the relationship between accessibility and economic development. ASCE, J. Urban Planning and Develop. **129**(2), 97–119 (2003)

Ozbay K., Ozmen D., Berechman J.: Contribution of transportation investments to county output. Transport Policy (under review) (2006)

''Real estate center.'' <http://recenter.tamu.edu/>

Waters, W.G.II.: Empirical Studies of Infrastructure Investment and Economic Activity: Evidence from Canada. World Conference on Transport Research, Istanbul (2004)

About the Authors

Dr. Joseph (Yossi) Berechman is a CN Chair Professor in Transportation and International Logistics, Sauder School of Business and SCARP, the University of British Columbia, Canada. Dr. Berechman has received his Bachelor degree from the Hebrew University in Jerusalem, Israel, and his Master and Ph.D. degrees from the University of Pennsylvania in Philadelphia. His major research interests are transportation economics and planning, transportation and land use, and transportation policy analysis.

Dr. Dilruba Ozmen holds a Bachelor's degree in Civil Engineering and Master's degree in Transportation from Middle East Technical University in Turkey, and a Ph.D Degree in Transportation from Rutgers University in New Jersey. Dr. Ozmen's main fields of interest are transportation engineering, planning, economics, land use and modeling. Currently she works as a Senior Transportation Engineer at Urbitran Associates.

Dr. Kaan Özbay is an Associate Professor in the Civil and Environmental Engineering Department at Rutgers University, New Jersey. Dr. Ozbay has received his B.S. in Civil Engineering from Bogazici University, Istanbul, Turkey, and his M.S. and Ph.D. Degrees in Civil Engineering (Transportation) from Virginia Tech. His research interests include advanced technology applications in Intelligent Transportation Systems, transportation economics, real-time traffic control methods, and application of operations research techniques to network problems.