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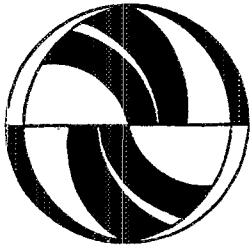https://escholarship.org/uc/item/1fn223q7

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Marlon G Boarnet

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Geography and Public Infrastructure

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Working Paper
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The University of California Transportation Center
University of California at Berkeley

Abstract

This paper examines the possibility of negative output spillovers from public infrastructure. A model of productive public capital shows that, when input factors are mobile, public infrastructure investments in one location can draw production away from other locations. In a linear production function framework, this effect would be manifested as a negative output spillover from public capital. Using data for California counties from 1969 through 1988, such negative spillover effects are shown to exist in the case of highway and street capital. The data show that changes in county output are positively associated with changes in highway and street capital within the same county, but output changes are negatively associated with changes in highway and street capital in other counties.

The effect of public capital on the private sector economy has been the subject of a large body of recent research. The question, argued vigorously by both policy analysts and econometricians, is whether public infrastructure enhances the returns to private factors of production. Yet for all the attention given to this topic, one important aspect of public capital has been somewhat overlooked. Public capital is provided at a particular place, and if such capital is productive, it enhances the comparative advantage of that location relative to other places. Thus one possible effect of public capital is to draw production into a relatively infrastructure-rich location, in part at the expense of more infrastructure-poor locations. That notion, formalized into a hypothesized negative spillover effect of public infrastructure, is the focus of this paper.

Section I: Background and Literature Review

The recent round of production function studies of public capital began with the metropolitan area studies of Eberts (1986), Deno (1988), and Duffy-Deno and Eberts (1991). That research generally found positive links between private sector economic activity and public infrastructure stocks. Yet attention soon gravitated toward Aschauer's analysis of national time series data. His estimates (e.g Aschauer 1989) suggested not only that public capital was productive, but that, at the margin, public infrastructure investment would yield higher returns than private sector capital investment. Aschauer's (1989) results also suggested that declining United States productivity growth could be explained in large part by the nation's reduced rate of investment in public infrastructure. Given that much political

discussion during the 1980s had focused on the advantages of the private sector over the public sector, Aschauer's results appeared to be a startling and important rebuke of at least one aspect of the prevailing political conventional wisdom.

What happened next has been summarized elsewhere (Gramlich 1994), so the discussion here will focus on aspects important to this research Criticism that the time series results were due to spurious correlations (Jorgenson 1991; Tatom 1991) led to increased use of state-level panel data. Most of the state studies, when corrected for unique state effects, showed no association between public capital stocks and private sector output or productivity (Evans and Karras 1994a; Garcia-Mila, McGuire, and Porter 1996; Holtz-Eakin 1994; Kelejian and Robinson 1994) The conclusion, which appears somewhat robust, is that with the necessary corrections for econometric problems, public capital has no marginal effect on output or productivity in a linear production function specification.[1]

Implicitly, the recent studies had a lot of geography in them. They used data which ranged from metropolitan areas (Deno 1988; Duffy-Deno and Eberts 1991; Eberts 1986) to panels of countries (Evans and Karras 1994b). Munnell (1992) even suggested an explicitly geographic consideration when she hypothesized that public capital has positive spillovers

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[1] This is consistent both with earlier research by Hulten and Schwab (1984, 1991) and with some cross-national studies of public infrastructure (e.g. Evans and Karras 1994b). Hulten and Schwab (1984, 1991) used a sources of growth methodology to apportion output growth in U.S. regions to changes in private inputs and changes in multi-factor productivity. They found that inter-regional differences in growth rates in the United States are largely explained by differences in the growth of private inputs in those regions This suggested that differential investments in public capital has little to do with the observed differences in growth rates across U.S. regions. Evans and Karras (1994b) found that public infrastructure stocks were statistically insignificant in a production function study that used panel data from seven countries.

across states. Yet Holtz-Eakin and Schwartz (1995) tested that hypothesis for the case of highway capital, and found no evidence of positive cross-state spillovers. If the Holtz-Eakin and Schwartz (1995) results suggest any spillovers, it is the possibility of *negative* cross-state spillovers from public capital. In their study, the spillover parameter is significantly negative in seven of twelve specifications.[2] This suggests the possibility of negative, rather than positive, spillovers from public capital.

Yet Holtz-Eakin and Schwartz (1995) focused on rejecting Munnell's hypothesis of positive spillovers, and most of the other public infrastructure literature has been concerned with estimating elasticities of private sector economic activity with respect to public capital. The concept of *negative* infrastructure spillovers, which, as the next section shows, is theoretically possible, has been relatively overlooked. This paper begins to bridge that gap. This research uses new data on economic output and highway and street infrastructure for California counties from 1969 through 1988 to examine possible negative spillover effects from highway and street capital. Before developing an empirical test of that hypothesis, a simple model of the geographic effects of public infrastructure will help clarify the key ideas.

Section II. The Model

This section will sketch a model of public capital in two cities, A and B. Each city

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[2] One should note that three of the specifications with significantly negative spillover parameters were estimated on levels rather than differences of the variables. Holtz-Eakin and Schwartz (1995) note that the levels specifications are potentially unreliable, since they do not control for unobserved heterogeneity. Excluding the levels specifications, the spillover parameter is significantly negative in four of the nine remaining regressions.

has one firm. Both produce identical products with identical technology. The output of both

firms is sold on the world market at price p. The supply of labor in each city is perfectly

inelastic in the short-run, although labor can migrate between cities in the long-run. Public

capital is an unpaid factor of production for firms in each city. In order to focus on the

productive effects of infrastructure, public capital will be assumed to be costlessly provided

in each city.[3]

To further simplify, firms use only one input, such that output is produced according

to

$$Q = \alpha\,(G)\,f\,(L)$$

where Q = output
G = public capital stock in the city
L = labor inputs employed by the firm
$\alpha'(G) > 0$
$f'(L) > 0$
$f''(L) < 0$.

The labor supply in each city is initially fixed at L_A and L_B. The public capital stocks

in the cities are G_A and G_B. Initially, let $L_A = L_B$ and $G_A = G_B$ Firms in both cities have a

demand for labor which is defined by the marginal revenue product of labor. The choice of

G is external to the firm, such that $\delta Q/\delta L = \alpha(G)f'(L)$. Labor supply and demand are

equilibrated when the firms hire at a wage equal to the marginal revenue product for the

fixed labor supplies in each city.

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[3] This might not be too far from the truth for highway capital, which is an important
component of the public capital variable in the empirical section that follows. Since
interstate highway projects are typically funded with 90% federal subsidies, those highways
might appear to be close to costless for localities

$$w_A = p \alpha (G_A) f'(L_A)$$
$$w_B = p \alpha (G_B) f'(L_B)$$

(2)

Assume that City A increases their endowment of public capital. From equation (2), it is clear that wages in A must increase. In the short-run, since labor in City A is a fixed factor, all the benefits of the increase in G will accrue to workers in City A in the form of higher wages. In the long-run, the wage differential between A and B induces labor migration from City B to City A. This is shown in Figure 1.

(Figure 1 somewhere near here.)

With labor migration, the new equilibrium is shown in boldface in the drawings in Figure 1. Labor supply increases in City A and decreases in City B until wages equilibrate at a new level, which is higher than the initial wage. Denote the increase in public infrastructure in City A as ΔG and the number of workers who migrated from B to A as ΔL. After the labor migration, output in A and B is

$$Q_A = \alpha (G_A + \Delta G) f(L_A + \Delta L)$$
$$Q_B = \alpha (G_B) f(L_B - \Delta L)$$

(3)

Given that, the increase in public capital in City A has the following long-run effects.

1. Wages increase in both cities.

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2. Labor increases in City A and decreases in City B.

3. Output produced in City A increases; output produced in City B decreases.

4. The marginal product of labor, which is $\alpha(G)f'(L)$, increases in both cities.[4]

5. Given result number 4 and the fact that the sum of labor in A and B is unchanged, total output in City A plus City B increases.

The point is that if public capital enhances the returns to mobile factors of production, infrastructure investments should shift output from infrastructure-poor to infrastructure-rich locations.[5] One could add complexity by modelling multiple factors, different types of public capital, or infrastructure that is funded with local (distortionary) taxes. Yet the intent here is simply to motivate the idea that public infrastructure can cause negative spillovers, literally drawing inputs (and thus production) away from areas which are relatively underinvested in public capital. Rather than focus on more elaborate models, the remainder of the paper gives evidence on an empirical question. Do the hypothesized negative spillovers really happen? That is examined in the next section by modifying a production function to test for negative spillovers from public capital stocks.

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[4] This follows since the marginal revenue product of labor must be the same in both cities in the long-run. Since the price of output in both cities is p, this implies that the marginal product of labor is the same in both cities in the long-run In other words, $\alpha(G_A+\Delta G)f'(L_A+\Delta L) = \alpha(G_B)f'(L_B-\Delta L)$ Given that $f''(L)<0$, the marginal product of labor in City B (and thus in City A) is higher in the long-run after the increase in public capital in City A.

[5] There are some similarities between this result and the large literature on tax competition among local jurisdictions (e g. Wilson 1986; Zodrow and Mieszkowski 1986). In property tax competition models, a reduction in one jurisdiction's property tax rate can draw mobile factors of production into the low tax city from other jurisdictions. In the model above, an increase in public infrastructure that does not require local funding draws mobile factors in from other locations Yet while tax competition models typically focus on the implications of factor mobility for the efficiency of public goods provision, the concern in the model given above is simply the effect of factor mobility on the location of production.

Section III. An Empirical Test

Description of the Test

If public capital enhances the returns to mobile factors of production, the theory in the preceding section shows that factors will migrate to areas with the best infrastructure stocks. Thus an investment in public capital will have both a direct effect, increasing output in the location that invests in public capital, and an indirect effect, decreasing output in other locations that experience an out-migration of factors to the infrastructure-rich location. In the context of an aggregate production function for a locality, total output can depend both on the stock of public capital in that locality (the direct effect) and the stock of public capital in other localities (the indirect effect). If the negative spillovers predicted in Section II exist, the direct and indirect effects will have opposite signs.

As mentioned earlier, both growth accounting studies and production function studies give little evidence that public capital influences output levels *across* states, but there have been no explicit tests of whether differential infrastructure stocks influence differences in output levels within states.[6] The purpose here is to formulate an explicit test of the hypothesis that public capital creates negative output spillovers within states.[7]

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[6] The metropolitan area studies of Deno (1988), Duffy-Deno and Eberts (1991), and Eberts (1986) used national samples of metropolitan statistical areas. The variation in those studies was both across and within states.

[7] This test is not necessary if one accepts as final the results of the growth accounting studies (Hulten and Schwab, 1984 and 1991) and state production function research (Evans

(continued ..)

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The test will be based on an aggregate production function for California counties, using data on all 58 counties in that state from 1969 through 1988. The county production function will be modified to include both a measure of the county's own stock of highways and roads and a measure of the stock of highways and roads in other counties in the state.[8] Thus the production function for a county is as shown below.

$$Q = f(L, K, H, H_o) \qquad (4)$$

where Q = private sector output in the county
L = labor inputs in the county
K = private sector capital stock inputs in the county
H = highway and street capital stock in the county
H_o = highway and street capital stock in other counties in the dataset

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[8] Highway capital stock and the stock of local roads are combined in this study, so that the independent variable measures the entire ground transportation capital stock in each county Note that the model in Section II does not include transport costs, so that model cannot illuminate how highway and street capital can provide a production advantage by facilitating cross-county trade. Restricting attention to within-county transportation benefits is more consistent with the discussion in Section II. Thus one might envision the advantage from highway and street capital as facilitating agglomeration benefits by allowing easier within-county movements of goods and persons.

The empirical test focuses on highway and street capital for several reasons. First, Gramlich (1994) shows that highway and street capital accounts for one-third of the public capital stock in the United States, and he builds a convincing argument that post-World War II trends in public capital are driven largely by changes in highway and street capital and changes in the educational building stock. Second, the negative spillovers hypothesized in this paper pose a potentially important policy issue for highway finance. Since many highways are funded with large state and federal subsidies, the existence of negative spillovers raises the specter that highway subsidies are, in part, advantaging some locations while disadvantaging other places in the same funding jurisdiction. This is discussed in more detail in the concluding section. Third, a focus on highway and street capital provides some comparability with Holtz-Eakin and Schwartz (1995), who examined cross-state spillovers from highway infrastructure. Fourth, the existence of reliable highway and street investment data for several years allowed construction of county highway and street capital stocks.

The production function in equation (4) includes the term H_o, which is highway and street capital in other counties. Of course, "other counties" must be defined in a sensible way. In the model in Section II, there were only two locations, such that the shift in output was clearly between those two places. More generally, with a large number of locations, one would expect public capital investment to enhance the position of a location *relative to other similarly situated places*. Negative spillovers, if they exist, ought to be most strong between places that are close competitors for economic activity. Thus the concept of "other counties" must be formalized to measure the extent to which counties are alternative locations for production. The way that counties relate to each other will be formalized after the

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regression specification is presented in the next section.

Model Specification

The regression model is based on a log-linear Cobb-Douglas aggregate production function for counties, shown below.

$$\log(Q_c) = \alpha_o + \alpha_1 \log(L_c) + \alpha_2 \log(K_c)$$
$$+ \alpha_3 \log(H_c) + \alpha_4 \log\left(\sum_{n=1}^{N_c} w_n H_n\right) + \varepsilon_c \qquad (5)$$

where Q = output
      L = employment inputs
      K = private sector capital stock
      H = highway and street capital stock

      "c" subscripts index counties
      "log" denotes natural logarithm

N_c is the number of other counties whose highway and street capital stock affects output in county "c". Thus the term $\sum w_n H_n$ is a weighted sum of highway and street capital stock in all counties where such infrastructure is judged to be important for output in county "c". For purposes of this paper, those other counties will be called "neighbor counties", even though they might not physically border on the county in question. Theory and common sense give some guidance in defining those neighbor relationships, as is described in the next sub-section.

The specification in equation (5) is similar to that used in Holtz-Eakin and Schwartz

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(1995). So far, the only difference is that the term $\Sigma w_n H_n$ restricts attention to the first round of neighbors. Holtz-Eakin and Schwartz defined neighbors such that second, third, and higher order neighbor effects were also measured.

Formally, Holtz-Eakin and Schwartz (1995) included the term $(I-\delta W)^{-1}H$, where I is an identity matrix and W is a matrix that defines how states (in the case of their study) neighbor each other Their formulation allows highway capital in one state to effect immediate neighbors in a "first-round effect", and then effect the neighbors of those immediate neighbors in a "second-round" effect, and so on. The parameter δ measures how the neighbor relationship decays from the "first round" or immediate neighbors, to neighbors of immediate neighbors, and so on The use of the term $\Sigma w_n H_n$ in equation (5) restricts attention to only immediate (or "first round") neighbors Either definition is consistent with the theory developed in Section II. The attention is restricted to first-round neighbor effects here because that allows a specification that is linear in the parameters, as opposed to the non-linear model in Holtz-Eakin and Schwartz (1995). One should also note that restricting attention to immediate neighbors is a more conservative test of spillovers, since any higher order neighbor effects are not measured.

Defining Neighbors

A fundamental issue in estimating equation (5) is choosing how to define the neighbors. For any particular county, what are the appropriate "other counties", and how ought the other counties be weighted? In other words, what are the w_n in equation (5)?

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Section II illustrates one way in which public capital can give a location a production advantage. As mentioned earlier, it is sensible to believe that any negative spillovers from infrastructure are strongest between those places that are close substitutes as locations for economic activity. Factors of production are more likely to move between similar places in response to advantages created by differential public capital stocks. Thus the neighbor relationship should capture the kind of similarity that might matter for within state economic competition.

The simplest, and most obvious, definition of such neighbor relationships would be based on sharing a common border, and such a definition is tested in the work that follows. Yet geographic contiguity is possibly not the best measure of how locations within a state compete for economic activity, and thus how those locations might experience negative spillovers from infrastructure investments elsewhere in the state.

For that reason, two other measures of the neighbor relationship are also used. One is based on population density. Those counties with similar population density are defined to be close neighbors. The assumption here is that factors move most easily between places that have the same degree of urban or rural character, as measured by population density. The other neighbor definition is based on per capita income. Again, places with similar incomes are assumed to be close economic competitors, and thus are classified as close neighbors. The weights for the three neighbor relationships are defined formally below.

1. Geographic Contiguity: $w_{i,j} = 1$ if counties "i" and "j" share a common border, 0 otherwise.[9]

2. Population Density:

$$w_{i,j} = \frac{1/|PDEN_i - PDEN_j|}{S_i}$$

$$where \quad S_i = \sum_j 1/|PDEN_i - PDEN_j|$$

$PDEN_i$ is population density, in persons per acre. in county "i" in 1980. The year 1980 is chosen because it is approximately in the midpoint of the data that are used to implement the model, and because the census year county population estimates are possibly more reliable.[10]

3. Per Capita Income·

$$w_{i,j} = \frac{1/|PCI_i - PCI_j|}{S_i}$$

$$where \quad S_i = \sum_j 1/|PCI_i - PCI_j|$$

PCI_i is per capita income in county "i" in 1980. The year 1980 is again chosen because it is in the middle of the data and because census year income estimates might be more reliable.

Given any of the three definitions for $w_{i,j}$, the term $\Sigma w_n H_n$ can be represented in

matrix notation by $W*H$, where W is a (58x58) matrix with elements $w_{i,j}$ and H is a (58x1)

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[9] Some authors (e.g. Case 1991; Holtz-Eakin and Schwartz 1995) have suggested normalizing the weights such that the sum of $w_{i,j}$ for any observation "i" equals one. Note that, due to the specification in equation (7), such a technique is equivalent to the {0,1} definition for weights given above. This is explained in footnote 14, with reference to the regression specification in equation (7), below.

[10] See Case, Hines, and Rosen (1993) for a similar treatment. Note that the term S_i normalizes $w_{i,j}$ such that the sum of the weights for any county, "i", equals 1.

column vector of county highway and street capital stocks. Thus the three different

definitions for $w_{i,j}$ correspond to three different weighting matrices, **W**.

Econometric Implementation

Previous production function research has established the importance of controlling

both for the effect of time and for unique effects associated with the geographic areas (Evans

and Karras 1994a; Garcia-Mila, McGuire, and Porter 1996; Holtz-Eakin 1994; Kelejian and

Robinson 1994). With that in mind, rewrite equation (5) as

$$
\begin{aligned}
\log(Q_{c,t}) &= \alpha_1 \log(L_{c,t}) + \alpha_2 \log(K_{c,t}) \\
&+ \alpha_3 \log(H_{c,t}) + \alpha_4 \log\left(\sum_{n=1}^{N} w_n H_{c,t}\right) + \gamma_t + f_c + \varepsilon_{c,t}
\end{aligned}
\tag{6}
$$

where "c" indexes counties and "t" indexes years
   Q, L, K, and H are as defined before
   w_n defines neighbor relationships in one of the three ways described above
   N is the number of counties, which is equal to 58
   γ is a vector of year-specific intercepts
   f is a vector of unique, time invariant, county effects
   and ε is an i i d. disturbance

As Holtz-Eakin and Schwartz (1995) note, using either deviations from means or

county dummy variables to estimate (6) identifies the parameters based on year-to-year

fluctuations. This could obscure the long-run relationship between output and public capital

(Munnell 1992) For that reason, Holtz-Eakin and Schwartz (1995) suggest transforming

equation (6) into what they call "long differences".

Subtracting the equation for the initial year from the equation for any other year, T,

gives

$$\log(Q_T) - \log(Q_0) = \alpha_1 [\log(L_T) - \log(L_0)]$$
$$+ \alpha_2 [\log(K_T) - \log(K_0)] + \alpha_3 [\log(H_T) - \log(H_0)] \tag{7}$$
$$+ \alpha_4 [\log(W*H_T) - \log(W*H_0)] + \gamma_T - \gamma_0 + \varepsilon_T - \varepsilon_0$$

where **W** is a (58x58) matrix of the w_n, defined in one of the ways described above, and the "c" subscripts have been suppressed.

If T is sufficiently far from the initial year, this captures the long-run relationship between the variables. Furthermore, equation (7) eliminates the fixed county effects. Following Holtz-Eakin and Schwartz (1995), long differences are formed for all t> = 6 (i.e. for all years 1974 through 1988, with 1969 being the initial year.) The resulting long differences are pooled, such that there are 870 total observations.

Holtz-Eakin and Schwartz (1995) further note that pooling the long differences induces serial correlation. For any two years "t" and "r", for county "c", the covariance between the error terms is

$$E(\varepsilon_{c,t} - \varepsilon_{c,0})(\varepsilon_{c,r} - \varepsilon_{c,0}) = \begin{array}{l} 2\sigma_\varepsilon^2 \quad if \ t=r \\ \\ \sigma_\varepsilon^2 \quad if \ t \neq r \end{array}$$

This information is used to get generalized least squares estimates of all regressions that follow. A pooled version of equation (7) was estimated for each of the three **W** matrices defined above. Results are given in the next section.

Section IV. Data and Results

Data on gross county product, employment, private capital stocks, and highway and street capital are available from 1969 through 1988. Gross county product is derived by apportioning state product to counties based on total county personal income, which is consistent with the methodology used by the Southern California Association of Governments to estimate county product within their region. Private capital stock is constructed by apportioning Munnell's estimates of California private capital to counties.[11] The apportioning methodology is the same as that used in Munnell (1990a), which in turn follows Da Silva Costa, Elson, and Martin (1987) Highway and street capital stock is constructed using a perpetual inventory method based on annual highway and street expenditures, in each county, starting in 1957. Employment in each county is available from the Census Bureau's *County Business Patterns* for each year See Boarnet (1995, Appendix A) for a detailed description of the data sources and the methods used to construct the county product, private capital, and highway and street capital variables.

Table 1 gives descriptive statistics of the logs and long differences of logs of all variables. Table 2 presents the results of estimating equation (7) using each of the three W matrices defined earlier.

(Tables 1 and 2 somewhere near here.)

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[11] I thank Douglas Holtz-Eakin and Alicia Munnell for providing the state private capital data

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Column 1 of Table 2 uses the **W** matrix that is based on geographic contiguity. The coefficients on labor and private capital are significantly positive (at better than the 1% level) The magnitude of the private capital variable is consistent with previous production function research that used state data, although the coefficient on labor is toward the low end of the range of elasticities obtained from state studies.[12] The coefficient on own county highway and street capital is also significantly positive at the 1% level. This is contrary to results of recent state level studies that used similar panel methodologies. One partial explanation is that highway plus street capital creates negative spillovers, such that any output effect is smaller at the state level than at the county level.[13] Yet the coefficient on neighbors' capital is insignificant in column 1. There is no evidence of negative spillovers across neighboring counties.[14]

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[12] See, e.g. Garcia-Mila and McGuire (1992), Garcia-Mila, McGuire, and Porter (1996), Holtz-Eakin (1994), and Holtz-Eakin and Schwartz (1995). The estimates for the elasticity of output with respect to labor were most often in the range of 0.6 to 0.7 in those studies, although Garcia-Mila and McGuire (1992) found coefficients on labor that are similar in magnitude to those reported in Table 2 of this paper. Yet Garcia-Mila and McGuire (1992) did not use unique state effects in their econometric specification.

[13] This can only be a partial explanation, since the model in Section II shows that, even with negative cross-county spillovers, if highway and street capital is productive for counties, it should also be productive, but with a smaller elasticity, for states.

[14] For any county "c", the variable **W*H** in column 1 is the sum of the highway and street capital in all counties that border on county "c". Holtz-Eakin and Schwartz (1995) suggested two extensions of the concept of geographic contiguity. First, they suggested that the neighbor variable be the average of highway capital in (in their case) bordering states. That is equivalent to defining $\bar{w}_{i,j} = 1/S_i$ if two counties share a border, 0 otherwise, where S_i is the number of counties that border county "i". If $w_{i,j}$ is an element of the (0,1) contiguity matrix defined in Section III, $\bar{w}_{i,j} = w_{i,j}/S_i$. Note that using $\bar{w}_{i,j}$ will not change the results of a regression based on equation (7). With a W matrix based on $\bar{w}_{i,j}$, for any county "i", the term $\log(\Sigma \bar{w}_j H_T) - \log(\Sigma \bar{w}_j H_0)$ becomes $[\log(1/S_i) + \log(\Sigma w_j H_T) - \log(1/S_i) - \log(\Sigma w_j H_0)]$, which is equivalent to using w_j as the weight. Holtz-Eakin and Schwartz (1995)

(continued...)

Restricting attention to geographic neighbors assumes that factors, and thus production, are mobile primarily between contiguous counties. This might not be the best way to formalize within-state economic competition. As an example, consider that Los Angeles County borders Kern County, a sparsely populated agricultural county in the San Joaquin Valley. Los Angeles County does not share a border with either San Francisco or San Diego counties. Yet Los Angeles County might easily be a closer economic competitor with San Francisco and San Diego counties than with Kern County. If so, the spillover effects of public capital might be based on a measure of similarity rather than the contiguity measure tested in Column 1.

Column 2 shows the results of using a W matrix based on the difference in population density between any two counties, as defined formally in Section III. The coefficients on labor, private capital, and highway and street capital are almost the same as in column 1, and all are statistically significant at the 1% level. Yet now the coefficient on neighbors' highway capital is significantly negative (also at the 1% level), suggesting some negative spillover across counties of similar population density.

Column 3 uses the W matrix that is based on differences in per capita income. Again, the coefficients on labor, private capital, and highway and street capital are largely unchanged. Now, the coefficient on neighbors' highway capital has a larger negative coefficient (suggesting that the spillover relationship is strongest between counties with

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[14](.. continued)
also tested a contiguity neighbor matrix that was adjusted to weight each neighbor's highway capital by the inverse of the share of that state in the land area of all neighboring states. The similar technique for counties was implemented, and the results do not substantively differ from those reported in Column 1 of Table 2.

similar per capita income), and the coefficient is again significant at better than the 1% level.

The results in Table 2 suggest a positive association between a county's own highway plus street capital stock and its output. The results also suggest and a negative association between neighbor's highway plus street capital stocks and own county output, so long as neighbors are defined based on population density or per capita income.

Absent a structural model of how highway funding is allocated to counties, there are still three reasons to believe that the relationships in Table 2 show the effect of highway and street stocks on county output, rather than any reverse causal link that runs from output to highway and street capital. First, the county fixed effects help control for the possibility that high income counties either invest more of their own resources in highways and roads or obtain more state funding. Second, using the vector autoregression techniques described in Holtz-Eakin, Newey, and Rosen (1986), changes in highway plus street capital stocks were regressed on lagged changes of both highway plus street capital stocks and county output. The null hypothesis that the coefficients on output equalled zero could not be rejected in regressions with two, three, four, or five lags, suggesting that the primary channel of causality does not flow from county output to highway capital stocks.[15] Third, since data were available on both total road miles and state highway miles in each county for most of the years in the sample period, log(H) was regressed on the ratio of state highway miles

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[15] Only regressions with two, three, four, and five lags were tested The test statistic follows a chi-squared distribution. For five lags, the statistic is 0.0032 with 5 degrees of freedom. For four lags, the statistic is 0.0026 with 4 degrees of freedom. For three lags, the statistic is 0.0039 with 3 degrees of freedom. For two lags, the statistic is 0.0011 with 2 degrees of freedom.

divided by total road miles.[16] The results were used to get a predicted value of log(H) for

each county for the years 1969 and 1974 through 1987. Long differences of the predicted

value of log(H) were then used in the regression shown in equation (7).[17] For all three W

matrices, using the predicted value of log(H) gives results which do not substantively differ,

either in sign or statistical significance, from those reported in Table 2.

Overall, the evidence supports the idea that highway and street capital influences

output in California counties, and that such infrastructure also creates negative spillovers

between counties of similar population density and per capita income. These results are from

a specification that uses differences of variables and county fixed effects, thus controlling

both for spurious correlations in levels of the variables and unobserved heterogeneity. The

implication of the results for both research and policy is discussed in the next section.

Section V. Discussion

The results given here conflict with prior research in two important ways. First, the

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[16] The data on state highway and total road miles are from the California Statistical Abstract.

[17] This amounts to using the ratio of state highway miles divided by total road miles as an instrument for log(H). The choice of an instrument for log(H) was constrained by the fact that the specification in equation (7) requires time-varying independent variables. Any time invariant characteristic of counties is subsumed into the fixed effect. The ratio of state highway miles divided by total road miles has the advantage of both varying over time and being largely influenced by exogenous factors such as geography, pre-existing development densities, and previous highway and road construction decisions Thus the ratio was assumed to be a valid instrument. The ratio of state highway miles divided by total road miles is generally smaller in the more urbanized counties. In 1987, the ratio ranges from 0.038 in San Francisco County to 0.218 in Amador County.

empirical tests suggest that highway and street capital creates negative output spillovers across counties, while prior research, when it has been concerned about spillovers at all, has focused on positive spillover effects. Proponents of infrastructure spending sometimes argued that, in the presence of positive spillovers from public capital, production function studies might better measure the productive effect of public infrastructure than traditional project benefit-cost analysis. Munnell (1992) further suggested that positive spillovers could explain how national time series studies (e.g. Aschauer 1989; Munnell 1990b) often found large elasticities of private output with respect to public capital, while state-level studies often found much smaller elasticities (e g. Garcia-Mila and McGuire 1992; Munnell 1990a). Yet, given the evidence presented here and in Holtz-Eakin and Schwartz (1995), a more reasonable explanation for the divergent results of national and state studies is that the large elasticities from national time series data were due to a failure to correct for spurious correlations in the levels of the variables.

Second, the coefficient on own county highway and street capital suggests that, for California counties, highway and street capital stocks are a significant determinant of output. The most recent state-level studies have found no link between public capital and private sector output in a production function framework (Evans and Karras 1994a; Garcia-Mila, McGuire, and Porter 1996, Holtz-Eakin 1994; Kelejian and Robinson 1994). The key characteristic of those recent state-level studies is that all used state fixed effects and estimated at least some specifications in differences [18] Yet this study also used fixed effects

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[18] Garcia-Mila, McGuire, and Porter (1996), after conducting a specification search, found that the preferred specification for state data is fixed effects estimated in differences.

and a differenced specification for county data, and found a positive link between county output and highway plus street capital stocks. Of course, with negative spillovers, any state-level effect would have a smaller magnitude than the own-county elasticity. Yet as the model in Section II makes clear, if infrastructure is productive for counties. it should still affect output for higher levels of geography. Thus a complete explanation of the divergence between these results and research on state panel data is a topic for further research.

Still, this research demonstrates that the geographic implications of location-specific public capital projects have been overlooked in the recent past. In the model developed in Section II there are output shifts induced by differential investments in public capital in the two cities. Yet in that model, employees at both locations benefit from any infrastructure investment, since labor mobility ensures that wage rates are equal in both cities in the long run. If the real world were that simple, there would be few reasons to worry about the locational impacts of public capital.

Yet if some factors are not mobile, the immobile factors in "infrastructure-poor" locations will not benefit from public capital investments elsewhere In the case of labor, even imperfect mobility, of the sort created by non-zero moving costs, could reduce the extent to which persons everywhere share in the returns to location-specific infrastructure projects Future theoretical and empirical work should examine how public capital (and also other location-specific projects) affect both mobile and imperfectly mobile factors of production.

Even without more detailed studies, some policy suggestions are prudent. First, the recent skepticism regarding the appropriateness of public capital as an engine of national

productivity growth (e.g. Holtz-Eakin 1993) ought not be discarded. In the presence of negative spillovers, the output effects of public capital projects can be smaller than even project benefit-cost analysis might suggest. More importantly, the geographic effects examined in this paper likely are different for different types of projects. If anything, the role of project analysis ought to be expanded to consider not only impacts in the immediate project area, but also any (possibly negative) spillover impacts in other areas.

Second, the implications of this work for project finance ought to be carefully considered Most highway projects are funded with large state and federal subsidies. Given negative spillovers, those projects might advantage some locations at the expense of other places within the same funding jurisdiction. Of course, the impact on employees and wages depends on the mobility of labor. Again, this reinforces the need for both careful project analysis and possibly for a more decentralized infrastructure financing policy. The cost of public capital investment ought to be borne by those who benefit, and the presence of negative spillovers suggests that some projects might actually disadvantage locations outside the immediate project area

Third, efficient pricing remains a promising infrastructure policy tool. In the case of highway capital, other authors have argued that peak period congestion pricing can be more efficient than further highway construction (e.g. Small, Winston, and Evans 1989, Winston 1990). Nothing in this study refutes that claim.

While all these points should remain part of the accumulated policy wisdom, this paper illuminates an important, and heretofore relatively overlooked, aspect of public capital. Location-specific projects have location-specific effects. For projects that enhance the

returns to private factors of production, theory suggests a redistribution of economic activity from locations with poor infrastructure stocks to those with more well developed stocks. The empirical evidence presented here supports that hypothesis. Future research should examine in more detail the geographic effects of location-specific public capital projects.

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Table 1: Descriptive Statistics

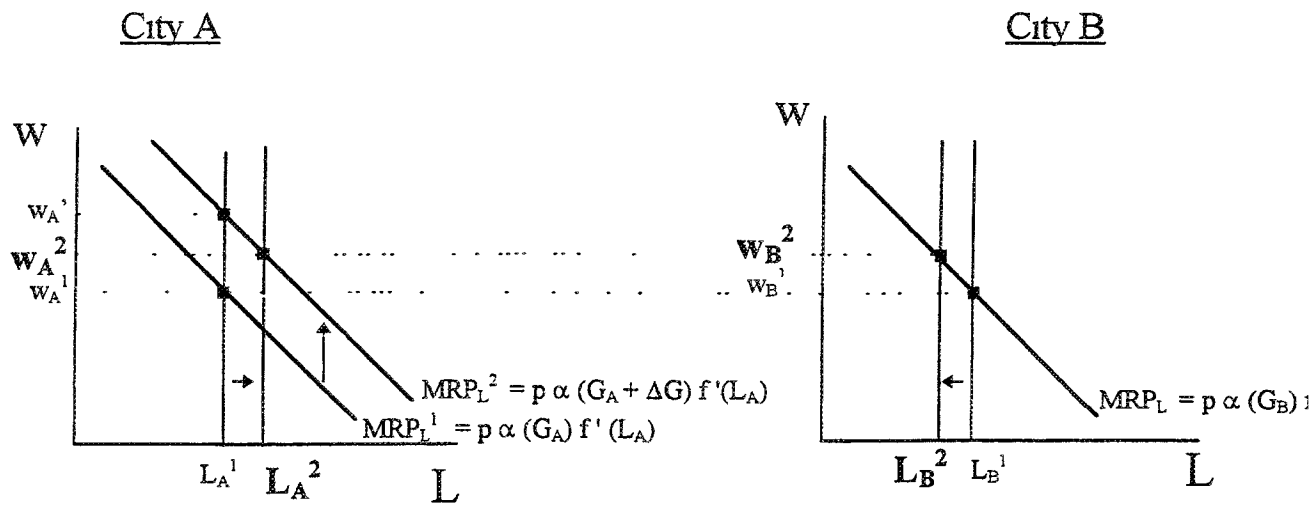| Variable	Mean	Standard Deviation	Minimum	Maximum
Levels				
Q: County Output	7.28	1.85	1.77	11.98
L: Employment	10.04	1.94	5.38	15.10
K: Private Capital	6.99	1.74	2.32	11.63
H: Highway and Street Capital	5.83	1.16	3.56	9.54
W_1*H	7.69	0.89	6.18	9.93
W_2*H	5.90	0 68	4.62	7.63
W_3*H	6.31	0 58	5.35	7.62
Long Differences				
Q: County Output	0.52	0.31	-0.12	1.62
L: Employment	0.58	0.49	-0.62	3.69
K. Private Capital	0.54	0.32	-0.74	1.54
H: Highway and Street Capital	0.23	0 15	-0.16	0.66
W_1*H	0.22	0 11	-0.03	0.60
W_2*H	0.21	0 09	-0.02	0 48
W_3*H	0.23	0.07	0.07	0.52

Note: Output, private capital, and highway and street capital are in logs of millions of dollars. Employment is in logs. Long differences cover 1974 through 1988, and are computed as difference from the natural log of the 1969 value W_1 is the geographic contiguity neighbor matrix; W_2 is the population density neighbor matrix; W_3 is the per capita income neighbor matrix The large values for the maximum long difference of county output and employment are due to the growth of three counties that started from a small base in 1969. All long differences greater than 1 5 for county output and employment are due to Alpine, Mono, and Nevada counties. Their 1969 population was 500 for Alpine, 5,200 for Mono, and 26,500 for Nevada County.

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Table 2: Regression Results
Dependent Variable = log(county output)

independent variable	column 1: contiguous neighbors	column 2: population density neighbors	column 3: per capita income neighbors
L (employment)	0.365 (0.021)	0.369 (0.021)	0.365 (0.020)
K (private capital stock)	0.217 (0.021)	0.224 (0.021)	0.213 (0.020)
H (own county's highway and street capital)	0.236 (0.052)	0.268 (0.052)	0.300 (0.052)
W*H (neighbor counties' highway and street capital)	-0.016 (0.078)	-0.307 (0.098)	-0.806 (0.140)
Number of Observations	870	870	870
R^2	0.67	0 67	0.69

All independent variables are in logs. All regressions are in long differences specification from equation (7) Standard errors are in parentheses. Coefficients on year dummy variables not shown.

Figure 1

City A — City B economic graphs

$MRP_L^2 = p\,\alpha\,(G_A + \Delta G)\,f'(L_A)$

$MRP_L^1 = p\,\alpha\,(G_A)\,f'(L_A)$

$MRP_L = p\,\alpha\,(G_B)$

Note Superscripts denote time periods The "1" superscript is before City A increases public infrastructure, the "2" superscript denotes the long-run equilibrium after City A increases public infrastructure The subscripts on w and L denote Cities