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Author
Boarnet, Marlon G.

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The University of California Transportation Center

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Berkeley, CA 94720

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Highways and Economic Productivity: Interpreting Recent Evidence

Marlon G. Boarnet

Department of Urban and Regional Planning
School of Social Ecology
University of California
Irvine, CA 92717-5150

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The University of California Transportation Center
University of California at Berkeley

Abstract: This paper reviews the recent literature on public infrastructure and economic productivity, with special attention to the particular case of highway infrastructure. Recent evidence suggests that, at the margin, highway infrastructure contributes little to state or national productivity. This is consistent with studies that show relatively small land use impacts from modern highways. Yet the idea that highways enhance economic health is common in the policy and planning communities. Two explanations can help reconcile this divergence between academic research and popular perception. First, some of the economic development observed near highways might not actually be caused by the highway. Second, some of the economic development near highways might be a shift of economic activity away from other areas. Either explanation suggests the need for reforms in highway project analysis and funding. Appropriate policy reforms and directions for future research are suggested.

Are highways economically productive? Recent research gives what appears to be an embarrassingly large number of answers, ranging from an enthusiastic "yes" to an emphatic "no". If the answer were only of interest within the scholarly community, the lack of consensus would be little more than an opportune source of research projects. Yet the effects of highway infrastructure are of great importance to the policy community, and it is here that one would wish to forge a consensus from a large and seemingly inconsistent literature. That consensus can be found, and its implications for highway project analysis and finance might surprise some within the transportation planning community.

I. Background: The Productivity Crisis and Production Function Studies of Public Capital

The recent debate on highway capital has been part of a larger debate on the economic impacts of all public capital. That debate hinged, at least in part, on learning what caused the slowdown in American productivity growth that began in the early 1970s.

Productivity is the sum of the value of all goods and services produced in a nation or region divided by a measure of inputs. Labor productivity is output per worker or per hours worked; capital productivity is output divided by the value of machinery and other capital investments. Multi-factor (or total factor) productivity is the residual obtained by subtracting from output growth that portion that can be attributed to growth in the amounts of labor and capital inputs. Multi-factor productivity is interpreted as output growth that is a result of technical or management innovations. (For a discussion, see Munnell 1990b, pp. 4-6.)

U.S. labor productivity grew at an annual average of 2.5% from 1948 through 1969 and 1.1% from 1969 through 1987 (Munnell 1990b; Krugman 1990, chapter 1). This slowdown is important because a nation's standard of living is fundamentally linked to its labor productivity. To a close approximation, nations can only grow wealthier (on a per capita basis) if their workers become more productive (i.e. there is an increase in labor productivity) or if they borrow. The borrowing can either be from future generations, in the form of government budget deficits, or from foreign countries, in the form of trade deficits. While both budget and trade deficits can have useful policy applications, few economists believe that large deficits in either area, if sustained over a period of time, are compatible with robust economic growth. Thus the only sure way to increase per capita wealth in the long run is to increase productivity (Krugman 1990, chapter 1; Krugman 1994, pp. 3-4).

The slowdown in American productivity growth in the early 1970s thus meant that the nation was growing wealthy less slowly. This was especially bothersome compared with the more robust growth of the earlier two decades. The serious implications of the lower rates of productivity growth gave rise to a sense that there was a "productivity crisis" -- a crisis that scholars sought to explain in hopes of finding policy solutions for the problem.

Several authors examined possible sources of slower U.S. productivity growth. (See, e.g. Baily 1981; Baily and Chakrabarti 1985; Baily and Gordon 1988; Denison 1979; Denison 1985; Griliches 1988; Griliches 1994; and Weisskopf, Bowles, and Gordon 1983.) The simplest summary of that work is that no explanation adequately accounted for the observed slowdown in productivity growth rates (Krugman 1990, chapter 1; Krugman, 1994, pp. 3-5). This left a vacuum, which David Aschauer stepped into in the late 1980s.

II. Production Function Studies of Public Infrastructure

Aschauer (1989) suggested that a decline in U.S. public capital (or infrastructure) investment contributed to the slowdown in productivity that began sometime in the late 1960s or early 1970s. Aschauer tested this idea with a production function study. A production function assumes that total output is related to inputs, often through a specific functional form. Aschauer modified a Cobb-Douglas production function to include public infrastructure stock. He estimated the coefficients of the production function using data on annual private sector output, labor inputs, private capital stock, and public capital stock in the United States for the years 1949 through 1985. He obtained estimates of the elasticity of private sector capital productivity with respect to public capital that were between 0.3 to 0.56. (All the estimated public capital elasticities were statistically different from zero at the 5% level or better.) In other words, a 10% change in the stock of public infrastructure would increase the productivity of private sector capital by from 3% to 5.6%. Transforming the functional form so that the dependent variable measured total factor productivity, Aschauer (1989) found elasticities of similar magnitude, and again all were statistically significant. This led him to conclude that the slowdown in productivity growth could be explained in large part by the falloff in American infrastructure investment that began in the mid-1960s. Since highways comprise 32% of all public capital (Gramlich 1994, p. 1178), the implication for ground transportation was obvious. Additional highway investment could provide a vital boost to the U.S. economy.

Aschauer's results were controversial almost from the outset, and his work spawned a large number of related studies. Those studies that used production functions can be grouped into three classes. Several initial studies used time series data, usually for the entire United States. (See, e.g., Aschauer 1989; Attaran and AuClair 1990; Munnell 1990b). Those time series studies typically found results similar to Aschauer's -- namely large and significantly positive links between public capital and U.S. economic output or productivity. A second group of studies used panel data on U.S. states (e.g. Garcia-Mila and McGuire 1992; Holtz-Eakin 1994; Holtz-Eakin and Schwartz 1995a; Holtz-Eakin and Schwartz 1995b; Kelejian and Robinson 1994; Munnell 1990a). The third group of studies (some of which predated Aschauer's influential 1989 paper) used data on a panel of U.S. metropolitan areas (Deno 1988; Duffy-Deno and Eberts 1991; Eberts 1986). The economic literature on public capital and productivity is discussed in Gramlich (1994). For that reason, the discussion here (and especially in later sections) will focus on interpreting the literature in ways that are relevant to the specific case of highway policy.

A. All Public Capital or Only Highway Capital?

Most production function studies focus on all public capital, yet that is not a large problem for those concerned only about the impacts of highway infrastructure. As mentioned earlier, in 1991, highway infrastructure was 32% of all non-military public capital in the United States (Gramlich 1994, p. 1178.) Thus highway capital is a large part of public capital, and Gramlich (1994) builds a strong argument that trends in the nation's total infrastructure stock are driven in large part by changes in highway and education spending.

More importantly, many authors tested the effects of different types of public capital. Often that involved looking only at highway capital, and other times that involved using a measure of "core" infrastructure. Depending on the study, core infrastructure included some or all of streets and highways, airports, mass transit infrastructure, electric and gas facilities, water and sewer systems, and education infrastructure.[1] Generally, the empirical results of any particular study do not vary depending on whether all infrastructure, core, or only highway infrastructure are used as an independent variable. In cases where there is a difference, highway capital tends to have a larger effect on productivity than other categories of public infrastructure (U.S. Department of Transportation 1992a). The evidence from studies of all public capital will be summarized, and evidence on the effect of only highways will be mentioned for those studies that included that measure.

Aschauer's work generated a large amount of criticism. The earliest complaints focused on the magnitude of the estimated public capital elasticities. Some analysts found those effects simply too good (or too large) to be true (Aaron 1990, pp. 52-53). More specifically, some author's questioned whether the time series results were due to a statistical phenomenon known as unit roots.

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[1] For studies that include highways in core infrastructure, see Aschauer 1989; Holtz-Eakin 1994; Kelejian and Robinson 1994. For studies that give separate estimates for highway infrastructure, see Aschauer 1989; Deno 1988; Garcia-Mila and McGuire 1992; Garcia-Mila, McGuire, and Porter 1996; Munnell 1990a; and U.S. Department of Transportation 1992a for a discussion.

B. Unit Root Problems with Time Series Studies of Public Infrastructure

Time series have unit roots if they display a consistent growth trend. (For a more formal discussion, see Davidson and MacKinnon, 1993, pp. 669-673.) Most macroeconomic time series, including output levels and public capital stocks, have trended upward since World War II. This common trend in both the output and public capital time series can lead to spurious correlations (Granger and Newbold 1974; Granger and Newbold 1986). The implication is that regression analysis will find potentially strong correlations between series even when no actual relationship exists; the series simply follow a common trend (Davidson and MacKinnon 1993, pp. 669-673). Formal tests for spurious correlations exist, and some rely on testing for the presence or absence of unit roots in the time series data (Davidson and MacKinnon, 1993, chapter 20).

Jorgenson (1991) suggested that the time-series evidence on public capital might be the result of spurious correlations. Tatom (1991) tested for unit roots in the time series production function regressions of output on public capital stock. He found that unit root problems were present, and could be corrected by taking the first difference of the equation. Simply put, this involves regressing changes in the dependent variable on changes in the independent variables, rather than using the levels of all variables. Once the appropriate correction was made, Tatom (1991) found no relationship between public capital and private sector economic output or productivity. Aaron (1990) and Kelejian and Robinson (1994) also found no statistically significant relationship between public capital and productivity when estimating first differenced regressions.

C. State and Metropolitan Area Studies

Other authors noted that the problem of spurious correlation could be overcome by relying less heavily on time series data. In particular, since 86% of all non-military public capital is owned by state and local governments (Gramlich 1994, Table 1, p. 1178), variation in infrastructure spending across states can be used to test the link to economic output. This cross-state variation has the advantage that it is not subject to the general macroeconomic trends that drive the time series output data, productivity data, and public capital data. Thus cross-state data can help alleviate the problem of spurious correlations caused by common trends in the time series data. (For a similar argument, see Holtz-Eakin 1994, p. 12.) Furthermore, the time series data can be sensitive to one or two turning points, or influential years (Aaron 1990), giving another reason why the additional information from cross-state data is desirable.

Munnell (1990a) first developed public capital stock estimates for U.S. states. Holtz-Eakin (1993b) later suggested revised estimates for state public capital. Munnell (1990a) estimated a production function on pooled time-series cross-section data on states. Garcia-Mila and McGuire (1992) used a similar technique. Both found significantly positive productivity effects from public capital. Yet in both studies, the magnitude of the coefficient on the public capital variable was considerably smaller than in the time series studies. This result was unchanged when both studies separated highway infrastructure from other public capital.

The size and significance of the public capital elasticity in cross-state studies was consistent with the pattern from earlier studies that used data from metropolitan areas (Duffy-Deno and Eberts 1991; Eberts 1986). Those studies found that infrastructure contributed to output with an estimated elasticity of 0.03 (Eberts 1986) and that infrastructure contributed to total personal income with an elasticity of 0.08 (Duffy-Deno and Eberts 1991).

Overall, the magnitude of any public capital effect seemed to get smaller with smaller geographic observations. The national studies usually yielded the largest infrastructure elasticities, while state and metropolitan area studies gave much smaller estimates. This prompted Munnell (1992) to suggest that public capital has cross-state spillovers which are not adequately captured with state or metropolitan data.

D. Positive Spillovers from Public Infrastructure

Munnell (1992) suggested that the smaller magnitude of the public infrastructure elasticity in state and metropolitan area studies could be explained by positive cross-state spillovers. She suggested that some of the productive effects of public capital might spillover across state borders, and thus state studies do not measure the full effect of infrastructure (Munnell 1992, p. 193-194).

Holtz-Eakin and Schwartz (1995b) explicitly tested whether state highway capital creates positive spillovers. They found no evidence for Munnell's hypothesis that public capital creates positive cross-state spillovers. While the idea of cross-state spillovers might have been attractive, it did not stand up to empirical testing. This is consistent with evidence reported in Gramlich (1990, p. 181) that on federal Interstate Highways in six selected states, two-thirds of all drivers were on within-state trips.

E. Controlling for Unique State Effects

The early cross-state studies (Munnell 1990a; Garcia-Mila and McGuire 1992) did not control for unique state effects which might influence both economic output and public capital. Some states might be wealthy for reasons that are difficult to quantify with available data. Those might be the same states that have large public capital stocks. In other words, cross-state data, by itself, does not eliminate the possibility that the correlation is not causal. Cross-state data simply changes the nature of the econometric problem (and the solution).

Since both state output and state capital stocks might be related to unique and unobservable state characteristics (e.g. state business climate), the most appropriate regression specification is to include unique state effects (Eisner 1991; Evans and Karras 1994a; Holtz-Eakin 1994; Garcia-Mila, McGuire, and Porter 1996). Those state effects can take the form of a dummy variable for each state or a component of the regression error term that is unique to each state. Of course, one needs panel data to estimate such a model, since the dataset must have more observations than there are states.

Holtz-Eakin's work is representative of the studies that used panel data. Holtz-Eakin (1994) estimated a production function with panel data on U.S. states from 1969 through 1986. He included state effects, both as dummy variables (known as fixed effects estimation) and as a component of the error term (random effects estimation). To control for the business cycle, he also included time trends or year dummy variables in various regression specifications.

Holtz-Eakin (1994) found that the effect of public capital was not significantly different from zero in any of the specifications that included state and time effects. This result was unchanged when a measure of core infrastructure that included highways was used as an independent variable. Holtz-Eakin and Schwartz (1995b) later showed that highway infrastructure is insignificant in a production function that controls for state and time effects.

These results are consistent with the work of Eisner (1991), Evans and Karras (1994a), Garcia-Mila, McGuire and Porter (1996), and Kelejian and Robinson (1994). All those studies found that public capital is not statistically significant in state production functions when state effects, year effects, and other appropriate econometric techniques are used. Using a similar panel methodology for seven countries for the years 1963 through 1988, Evans and Karras (1994b) also found no statistically significant effect from public capital. Garcia-Mila, McGuire, and Porter (1996) obtained insignificant public capital elasticities when separating highway capital from other public infrastructure in a panel study, and Kelejian and Robinson (1994) got the same result when using a measure of core infrastructure that included highways.

This is also consistent with earlier work by Hulten and Schwab (1984, 1991) who used a "sources of growth" framework rather than a production function methodology. Sources of growth apportions output growth to changes in private inputs and changes in multi-factor productivity. In this framework, multi-factor productivity includes both public capital growth and technological change. Hulten and Schwab (1984, 1991) found that inter-regional differences in growth rates in the U.S. are largely explained by differences in the growth of private capital and labor inputs in those regions. They concluded that differential investments in public capital had little to do with differences in growth rates across U.S. regions.

F. Endogeneity and the use of Aggregate Data

A regression analysis of a national, state, or metropolitan area production function uses a measure of output (or output divided by inputs) as the dependent variable, with a measure of public capital stock as an independent variable. This raises an important specification issue, since the capital stock must be exogenous to the economy for ordinary least squares (OLS) to be valid. There are two ways to get insight into this endogeneity issue. One is to test whether economic output causes public capital investment, since such reverse causality clearly violates the OLS assumptions. The second is to instrument the possibly endogenous variable (public capital) with a variable that is exogenous to the economy.

Granger (1969) proposed a causality test which involves regressing leads and lags of one time series variable on another. If past values of one variable, call it x, are statistically significant in a regression of y on x, x is said to Granger cause y. (Technically, lagged values of y should also be included in the regression. See the discussion in Sims 1972.) This technique was adapted to private and public sector capital investment by Eberts and Fogarty (1987). While their results vary based on region and time period, they generally find evidence of causality in both directions. In other words, public capital investment both causes and is caused by private capital investment. This reinforces the notion that public infrastructure is endogenous to the economy.

Some researchers used instrumental variables to account for this endogeneity in production function studies. (See, e.g. Garcia-Mila and McGuire 1992; Holtz-Eakin 1994; Kelejian and Robinson 1994.) In two of those studies (Holtz-Eakin 1994; Kelejian and Robinson 1994) the public capital variable is not significantly different from zero in the instrumented regression.

G. Summary of Econometric Production Function Studies

Overall, these results cast considerable doubt on the role that public capital plays in the private sector economy. Once the appropriate econometric techniques are used, even the time series evidence usually shows no statistically significant productivity effect from public capital (Tatom 1991). Later cross-state studies verify this result. When controlling for unique state and year effects, which in general is the preferred approach, recent studies find no statistically significant effect from public infrastructure (Evans and Karras 1994a; Garcia-Mila, McGuire, and Porter 1996; Holtz-Eakin 1994; Kelejian and Robinson 1994). These results are the same when only highway capital is used as an independent variable (Holtz-Eakin and Schwartz 1995b).

The metropolitan area studies have not been adjusted to control for unique metropolitan area effects, so it is unclear if their results would be statistically significant once techniques similar to those in Evans and Karras (1994a) or Holtz-Eakin (1994) are used.

The most reliable studies (i.e. those that control for unit roots and unique state effects) show no productive role, at the margin, for public capital. This is not to say that public capital has no impact on the private sector economy; rather it simply suggests that, in terms of overall United States economic performance, there is no shortage. One must also note, as Holtz-Eakin (1994) explicitly has, that public capital provides user benefits above and beyond any economic impacts. New roads can move more persons or reduce travel times; sewer systems provide sanitation benefits; other public capital projects yield a host of amenities. The empirical evidence suggests that, at the margin, it is those user benefits, rather than economic impacts, which should provide the justification for expanded infrastructure investment.

Yet the criticisms of the public infrastructure literature do not end with the econometric concerns summarized above. In many ways, that is only the beginning.

III. The Mismatch Between Policy and Research

Some authors suggested that there is a sizeable infrastructure shortage in the United States, based in part on the results of the early time series studies. (See, e.g., Aschauer 1993; Kaplan 1990; Lerner 1992; Nathan 1992.) This idea was part of Bill Clinton's 1992 presidential campaign, even though his infrastructure investment package was defeated in Congress in 1993. Yet without considering the econometric issues summarized above, there are still two reasons to be cautious when discussing infrastructure policy.

The first issue is that the available evidence, based on aggregate data (often at the level of states or the nation), cannot give any insight into the wisdom of particular projects.

Even if there were a shortage of public capital, a broad program to finance more infrastructure could include a large number of unwise projects. Many have argued that the appropriate response is not to increase infrastructure funding across the board, but rather to continue and even reinforce careful project evaluation (Gramlich 1994; Holtz-Eakin 1993a; Holtz-Eakin 1993c). To the extent that the production function research distracts attention from the analysis of individual projects, it thus diverts attention from an important policy issue.

The second point is that, if infrastructure is productive, it is because of the services that the stock of capital produces (Forkenbrock 1990; Kessides 1993). Those services could be increased not only by building more stock, but also by using the existing stock more efficiently. Since almost all available research on public capital has measured only the value of the stock rather than the services produced by the infrastructure, the policy recommendations from that literature are likely to overlook possibilities for achieving economic gains by using the existing stock more efficiently.

This issue is especially important in the case of highways. For years scholars have argued that urban highways, especially when congested, are underpriced. (See., e.g., Keeler and Small 1977; Mohring and Harwitz 1962; Small 1983; Small, Winston and Evans 1989; Vickrey 1963.) Given that, an especially promising approach to increasing accessibility in congested urban areas is to price highways more efficiently rather than build more freeways (Downs, 1992, Chapter 4; Winston 1990). Again, the production function studies of public capital run the risk of diverting attention away from this important issue.

Both the project analysis and pricing criticisms contend that production function research actually diverts attention away from important policy issues. In terms of congestion pricing, the point is very well taken, and there have been few if any responses that argue that pricing should be ignored for economic reasons. (On the other hand, many persons have questioned the political feasibility of congestion pricing. For various viewpoints in that discussion, see Downs 1992, Chapter 4; Small 1993; Small, Winston, and Evans 1989; and Wachs 1994.) Yet the issue of project analysis is more problematic.

If public capital generates cross-state or cross-region spillovers, then looking at any one project will understate the benefits of public capital. Even though Holtz-Eakin and Schwartz (1995b) provide evidence that highway productivity benefits do not spill over across state borders, absent other corroborating evidence one might still be concerned that traditional benefit-cost studies will not measure the full economic impact of a project. If there are productivity spillovers from highways, production function studies, since they can measure spillovers from any one project, are actually better suited than benefit-cost analysis to study economic impacts. Thus the choice between aggregate production functions and individual project analysis depends on a clear assessment of the nature of the services provided by highway infrastructure.

IV. Highway Networks and Spillover Benefits

Highway investments create accessibility by connecting several different locations. Since the number of destinations that can be reached is an important aspect of accessibility, highways are characterized by network externalities.

Before a network is complete, connecting additional locations increases the usefulness of the entire network. Thus a new highway in a partially built network increases the accessibility provided by all the other highways in the network. (This phenomenon is rather general, and applies to other goods provided by a network, such as telephone and airline services, and even to goods where consumption is enhanced if others also consume the good. See, e.g., Pindyck and Rubinfeld, 1992, pp. 118-120.) Stated differently, since a new road makes the entire network more useful, the new road creates positive spillovers (in increased accessibility) throughout the network.

As a network nears completion, the strength of any network externalities from additional network construction can decrease. For highway networks, a new or improved road within an already largely complete network might create accessibility benefits within the immediate area, but there will likely be few spillover benefits throughout the network. (For a discussion of this concept, see Giuliano 1989.)

The link between accessibility and productivity impacts must be a close one, since the economic value of highway investment is in the accessibility that such investment provides (Kessides 1993; U.S. Department of Transportation 1992a). One would expect productivity spillovers in cases where new highway projects improve accessibility throughout a large network. Thus examining how modern highway projects affect accessibility can give some insight into whether project analysis will measure all of the productivity impacts of highways.

A. Evidence on the Accessibility Impacts of Modern Highway Projects

Direct evidence on the accessibility impacts of highways is hard to find, but fairly good indirect evidence can be obtained by measuring land use impacts near highways. The monocentric urban model predicts a close relationship between transportation improvements and land use. (See, e.g., Fujita 1989.) More complicated multi-centric models retain the same qualitative relationship between land use and accessibility (White 1976; Wieand 1987; Yinger 1993). While there are difficulties inherent in using land use as a measure of accessibility, the existence of a link is commonly accepted.

Giuliano (1989) summarized the literature on land use impacts of highways. She notes that those impacts, regardless of how measured, appear to be decreasing over time. In general, the studies that found sizeable impacts (e.g. Mohring 1961; Czamanski 1966) examined the first freeway constructed in a metropolitan area. Those early studies measured the impact of the first round of Interstate Highway construction, which one might expect had sizeable network externalities.

By the early 1970s, the Interstate Highway system was essentially complete. The highway building task changed from network construction to network maintenance. Theoretically, this suggests accessibility impacts that are more localized to an area near the project. Giuliano (1989, pp. 151-152) was explicit in suggesting that modern highway projects improve accessibility in the immediate area, rather than throughout the network. She suggested that this explained the small and often negligible land use impacts found in more recent highway studies (e.g. Payne-Maxie Consultants 1980).

B. Implications for Empirical Work

The implication for measurement is that, in most U.S. urban areas, there are likely to be few spillover benefits from highways beyond an immediate project area. This is consistent with Holtz-Eakin and Schwartz (1995b), who found no evidence of cross-state productivity spillovers from highway capital. Network economies were likely important in the early round of Interstate Highway building, but appear to be less important now. Given that, a focus on project analysis is important, as suggested by Gramlich (1994) and Holtz-Eakin (1993a).

Furthermore, the evidence that suggests current highway construction produces relatively small and localized accessibility changes (Giuliano 1989) agrees with the studies that find public capital has no marginal effect on productivity or economic output. Both are consistent with the well developed infrastructure stock in the United States. It is possible, and the evidence suggests, that network economies have been exhausted and further construction of highway infrastructure will produce little additional economic gains. Yet if the evidence is consistent on this point, the policy community might be just as consistent in holding a contrary opinion.

V. Highways and Economic Growth

The idea that highways bring permanent economic benefits is a popular one. As of 1986, 36 states included an assessment of economic benefits as part of their highway benefit-cost analysis (Forkenbrock and Plazah 1986). States such as Iowa (Forkenbrock and Foster 1990) and Minnesota (Dalton 1991; Weisbrod and Beckwith 1992) have adopted highway policies with the explicit purpose of furthering economic development. Highway benefit-cost analyses have documented economic gains (Dalton 1991; Forkenbrock and Foster 1990; Seskin 1990). Lastly, a large number of studies have found that highways are a statistically significant factor in explaining growth patterns within and across U.S. metropolitan areas. (See, e.g., Boarnet 1994; Carlino and Mills 1987.) How can this evidence be consistent with the idea that highways are not, at the margin, economically productive?

There are several possible explanations which can reconcile the popular belief that highways bring economic benefits with the empirical evidence on infrastructure and productivity. One possibility is that highway benefit-cost analyses quote economic benefits which are exaggerated to serve political purposes. Certainly benefit-cost analyses can be manipulated, and the misuse of analytical tools has been documented in other instances involving transportation policy. (See, e.g., Kain 1990 and Pickrell 1992 regarding rail transit). Yet to explain the entire mismatch as a result of flawed benefit-cost analyses risks being overly simplistic.

Another possibility is that the local economic benefits of highway projects are based on real phenomena. Local officials see businesses and growth flocking to new highways, and in many areas such phenomena are not simply figments of some politician's imagination. As mentioned earlier, many studies have documented a link between growth patterns and highway location. Yet there are two reasons why that might not mean that highways cause economic growth.

The first reason is the causality issue discussed earlier. Highway locations are often planned for areas where future growth is projected. Thus it might not stretch the truth to say that economic growth causes the highway, rather than vice versa. Furthermore, if highway construction during the early Interstate era did cause economic development nearby, the typically slow adjustment of residence and firm locations within urban areas could cause that growth to be observed several years later. Based on a lagged adjustment model, Carlino and Mills (1987), Grubb (1982), and Luce (1994) estimated that urban residence and firm locations take from 10 to 50 years to adjust to a new equilibrium. Thus even if only the first round of Interstate Highway construction had economic impacts, the household and firm movements observed today could be an artifact of those initial impacts, rather than the result of current highway projects.

The second issue concerns the possibility that highway capital shifts economic activity from one area to another. If highways confer a production advantage on a particular location, firms can be expected to respond to that advantage by moving to that location. Thus some of the growth that is observed near highways could be a shift of economic activity that would have occurred elsewhere (Forkenbrock and Foster 1990).

Stephanedes and Eagle found evidence that highways contributed to economic growth in urban Minnesota counties in part at the expense of other counties in the state (Eagle and Stephanedes 1987; Stephanedes 1990; Stephanedes and Eagle 1987). Rephann and Isserman (1994), when comparing counties on an Interstate Highway with those that had no Interstate, showed that only counties with some prior urbanization realized economic benefits from Interstate Highways. While Rephann and Isserman (1994) did not examine whether

Interstates redistributed growth from non-urban counties, their evidence on geographic variation in highway benefits is consistent with the results of Stephanedes and Eagle. The evidence on redistributed growth is also consistent with the results of Boarnet's (1995b) production function study of California counties. Using data from 1969 through 1988, Boarnet (1995b) found that economic output in California counties is positively related to the amount of highway capital in the county, but negatively related to highway capital in neighboring counties.

Overall, these results suggest that some of the economic growth observed near highways could be a redistribution of growth that would have occurred elsewhere. Even if economic development near highways is not a redistribution from other locations, it might be an artifact of highway projects built years earlier.

Either of these two explanations are consistent with economic growth near highway projects. Yet at best it would be incomplete to conclude from that growth that the highway caused the economic impacts. For example, if some of the increased economic activity is a shift from another location, economic benefits will be overstated by looking only within the immediate project area.

The question of whether or not to count economic benefits when evaluating highway projects is a crucial one. In the case of one project in Minnesota, almost half of all project benefits were permanent economic impacts (Weisbrod and Beckwith 1992). For that project, if economic benefits are included, the benefit/cost ratio was greater than one for each of eight possible corridor enhancement alternatives. Without economic benefits, the benefit cost ratio was less than one in five of the eight cases (Weisbrod and Beckwith 1992, pp. 76-77).

Forkenbrock and Foster (1990) show that in the case of a proposed highway from St. Louis to St. Paul, including highway benefits changes the preferred route selection if one chooses the route with the highest present value of benefits minus costs. Seskin (1990) similarly shows that, for proposed highway projects in Wisconsin, Massachusetts, and Indiana, economic benefits are often estimated to be larger than the value of road user benefits. In the case of the Wisconsin project (a proposed highway from Green Bay to St. Paul Minnesota), the inclusion of economic benefits was necessary to justify the project in a benefit-cost analysis (Seskin 1990).

Forkenbrock and Foster (1990) argue that economic benefits should not be included in project analysis, precisely because those benefits likely represent a shift in economic activity rather than new growth. This view is consistent with much of the evidence given above.

A full reading of the evidence on highways, productivity, and broader economic and land use impacts suggests considerable caution when evaluating highway-related economic benefits. There is ample evidence to suggest that both the accessibility and economic impacts of highways are rather localized. While the early period of Interstate Highway building might have involved considerable network externalities, the network is now built. The empirical evidence suggests that much current highway construction creates, at best, localized economic impacts.

VI. Policy Implications

The policy implications of this are several. First, as mentioned above, estimates of economic benefits from highway projects should be viewed cautiously. Second, the policy community should give more attention to the possibility that economic benefits can be better achieved by using highway infrastructure more efficiently, rather than by pouring more concrete.

Virtually all the empirical evidence summarized above examines the value of the highway capital stock, not the accessibility provided by that stock. Thus there is nothing in the above evidence that contradicts the notion that sound congestion pricing, by more efficiently using the available highway capital, can yield economic benefits. In fact, one study that included a measure of highway congestion in a production function study found that reduced congestion is associated with more economic output (Boarnet 1995a). Since, as Giuliano (1989) noted, building more highways often has only a small impact on network accessibility, pricing policies might be a more fruitful way to increase accessibility, and thus possibly generate economic impacts.

Third, the link between highway funding and economic benefits ought to be more closely examined. Most highway projects in the United States are funded with large federal subsidies (usually 90% of cost for Interstate projects.) To the extent that economic benefits are used to help justify some projects, this raises the specter that federal funding is being used at least in part to finance economic impacts which might be illusory or, at best, very localized. Furthermore, if localities can receive state or federal subsidies for projects that cause economic losses elsewhere, some locations might help pay for projects that will undermine economic growth in their own area. Absent any conscious decision to use highway funding to redistribute wealth, this would be inappropriate.

When thinking about reforming the role of state and federal subsidies in highway funding, two solutions are possible. Either scale back the use of economic benefits in highway project evaluation (as discussed above and advocated by Forkenbrock and Foster 1990) or scale-back federal funding arrangements (as suggested in Gramlich 1994). Which solution is best is an important topic for future research.

The important point is that there should be a correspondence between the geographic incidence of highway project benefits and the geographic split of funding responsibilities. State and federal subsidies are still appropriate for network maintenance and to pay for the benefit of moving freight and passengers throughout the state or national highway system. Yet economic benefits which are localized are best funded through local sources.[2]

Federal highway funding arrangements reflect a view of highways that might have been appropriate in the early days of Interstate Highway construction. At that time there was great value in constructing the initial network, and the benefits accrued to the whole nation. Now that the network has been constructed, such that current projects often do not exhibit strong network externalities, serious thought should be given to changing funding arrangements.

One possible direction for reforming funding policy would be to expand the focus on local funding that already exists, albeit in small ways, in the Intermodal Surface Transportation and Efficiency Act of 1991 (ISTEA). ISTEA increases the ability of local governments to enter into public-private highway partnerships (U.S. Department of

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[2] For a similar argument in favor of a geographic correspondence between highway benefits and funding responsibilities, see Forkenbrock (1990). Netzer (1992) also argues for decentralized funding arrangements for highways.

Transportation 1992b). To the extent that such arrangements allow localities to pursue economic benefits with local funding, it is a step forward. Furthermore, to the extent that such partnerships result in peak period toll facilities, the policy of efficient highway pricing will also be furthered.

Yet the public-private provisions in ISTEA represent a small step. Federal funding for such projects can, in some cases, be as high as 80% (U.S. Department of Transportation 1992b). This likely reflects the thinking of an earlier era, when the network externalities of highway construction were larger. It is possible that the geographic distribution of benefits from modern projects makes more local funding appropriate.

Future research should study ways to expand the public-private highway provisions of ISTEA in an attempt to encourage a close link between local economic benefit assessment and local funding. If localities wish to use highways for economic benefits, they should pay for those benefits themselves. Of course, federal and state funding should remain for network maintenance and for benefits that accrue to the nation and state.

In general, funding responsibilities should correspond to the geographic distribution of benefits. Local funds should pay for local benefits, and state or federal funds should pay for systemwide or network benefits. Since the distribution of local, state, and national benefits likely varies from project to project, the appropriate funding split also likely varies across projects. This suggests a move away from the standard subsidy rules of current practice.

This, in turn, suggests a close link between project analysis and funding responsibilities, which will place a considerable analytical burden on project analysis. Both future research and practice should attempt to develop benefit-cost analyses that not only measure who benefits but, especially in terms of economic impacts, whether those benefits are either growth that would have occurred without the project or growth that is a shift from other areas. That assessment should then be carefully applied not only to decisions about whether to build the highway, but also to decisions about how funding responsibilities are split between federal, state, and local authorities.

VII. Conclusion

The evidence suggests that, at the margin, highway infrastructure has little effect on national or state productivity. This is consistent with evidence on land use impacts which suggests that modern highways often create only small changes in network-wide accessibility within a metropolitan area. Both the productivity and land-use studies suggest that highway building in the United States has entered a new era. The Interstate Highway system is essentially complete and, in many urban areas, the network externalities of further highway construction have been largely exhausted.

Projects that appear to generate large amounts of growth either may not actually cause that growth or may cause it in part by shifting economic activity from other areas. Both highway funding arrangements and project analysis should be examined carefully in light of that possibility.

Bibliography

Aaron, Henry J. 1990. Discussion of "Why is Infrastructure Important?" In *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Proceedings of Federal Reserve Bank of Boston conference, June 1990.

Aschauer, David Alan. 1989. Is Public Expenditure Productive? *Journal of Monetary Economics* 23: 177-200.

Aschauer, David Alan. 1993. Public Capital and Economic Growth. In *Public Infrastructure Investment: A Bridge to Productivity Growth?* Public Policy Brief Number 4. The Jerome Levy Economics Institute of Bard College.

Attaran, Kazem and Phillippe Auclair. 1990. Highway Stock and Private-Sector Productivity. *Transportation Research Record* number 1274.

Baily, Martin Neil. 1981. Productivity and the Services of Capital and Labor. *Brookings Papers on Economic Activity* 12: 1-50.

Baily, Martin Neil and Alok K. Chakrabarti. 1985. Innovation and Productivity. *Brookings Papers on Economic Activity* 16,2: 609-639.

Baily, Martin Neil and Robert J. Gordon. 1988. The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power. *Brookings Papers on Economic Activity* 19,2: 347-420.

Boarnet, Marlon G. 1994. An Empirical Model of Intrametropolitan Population and Employment Growth. *Papers in Regional Science, The Journal of the RSAI* 73,2: 135-152.

Boarnet, Marlon G. 1995a. The Economic Effects of Highway Congestion. University of California, Irvine, mimeo., September, 1995.

Boarnet, Marlon G. 1995b. Transportation Infrastructure, Economic Productivity, and Geographic Scale: Aggregate Growth versus Spatial Redistribution. University of California Transportation Center working paper number 255. Berkeley, California: University of California Transportation Center.

Carlino, Gerald A and Edwin S. Mills. 1987. The Determinants of County Growth. *Journal of Regional Science* 27: 39-54.

Czamanski, Stanislaw. 1966. Effects of Public Investments on Urban Land Values. *Journal of the American Institute of Planners* 32: 204-217.

Dalton, Douglas F. 1991. Wisconsin's Corridors 2020: Highway Planning for Economic Vitality. *ITE Journal*, October, 1991, pp. 21-24.

Davidson, Russell and James G. MacKinnon. 1993. *Estimation and Inference in Econometrics*. Oxford: Oxford University Press.

Denison, Edward F. 1979. *Accounting for Slower Economic Growth: The United States in the 1970s*. Washington, D.C.: The Brookings Institution.

Denison, Edward F. 1985. *Trends in American Economic Growth, 1929-1982*. Washington, D.C.: The Brookings Institution.

Deno, Kevin T. 1988. The Effect of Public Capital on U.S. Manufacturing Activity: 1970 to 1978. *Southern Economic Journal* 53: 400-411.

Downs, Anthony. 1992. *Stuck in Traffic: Coping with Peak-Hour Traffic Congestion*. Washington, D.C.: The Brookings Institution.

Duffy-Deno, Kevin T and Eberts, Randall W. 1991. Public Infrastructure and Regional Economic Development: A Simultaneous Equations Approach. *Journal of Urban Economics* 30: 329-343.

Eagle, David and Yorgos J. Stephanedes. 1987. Dynamic Highway Impacts on Economic Development. *Transportation Research Record* number 1116, pp.56-62.

Eberts, Randall W. 1986. Estimating the Contribution of Urban Public Infrastructure to Regional Growth. Working Paper number 8610. Cleveland, Ohio: Federal Reserve Bank of Cleveland.

Eberts, Randall W. and Michael S. Fogarty. 1987. Estimating the Relationship Between Local Public and Private Investment. Working Paper number 8703. Cleveland, Ohio: Federal Reserve Bank of Cleveland.

Eisner, Robert. 1991. Infrastructure and Regional Economic Performance: Comment. *New England Economic Review*. September/October 1991, 47-58.

Evans and Karras. 1994a. Are Government Activities Productive? Evidence from a Panel of U.S. States. *Review of Economics and Statistics* 76,1: 1-11.

Evans and Karras. 1994b. Is Government Capital Productive? Evidence from a Panel of Seven Countries. *Journal of Macroeconomics* 16,2: 271-279.

Forkenbrock, David J. Putting Transportation and Economic Development into Perspective. *Transportation Research Record* number 1274.

Forkenbrock, David J. and Norman S. J. Foster. 1990. Economic Benefits of a Corridor Highway Investment. *Transportation Research A* 24A,4: 303-312.

Forkenbrock, David J. and D. J. Plazah. 1986. Economic Development and State-Level Transportation Policy. *Transportation Quarterly* 40,2: 143-157.

Fujita, Masahisa. 1989. *Urban Economic Theory: Land Use and City Size*. Cambridge, England: Cambridge University Press.

Garcia-Mila, Teresa and Therese J. McGuire. 1992. The Contribution of Publicly Provided Inputs to States' Economies. *Regional Science and Urban Economics* 22: 229-241.

Garcia-Mila, Teresa, Therese J. McGuire, and Robert H. Porter. 1996. The Effect of Public Capital in State-Level Production Functions Reconsidered. *Review of Economics and Statistics* forthcoming.

Giuliano, Genevieve. 1989. Research and Policy Review 27: New Directions for Understanding Transportation and Land Use. *Environment and Planning A* 21: 145-159.

Gramlich, Edward M. 1994. Infrastructure Investment: A Review Essay. *Journal of Economic Literature* 32:1176-1196.

Granger, Clive W. J. 1969. Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Econometrica* 37,3: 424-438.

Granger, Clive W. J. and Paul Newbold. 1974. Spurrious Regressions in Econometrics. *Journal of Econometrics* 2: 111-120.

Granger, Clive W. J. and Paul Newbold. 1986. *Forecasting Economic Time Series*, Second Edition. Orlando, Florida: Academic Press.

Griliches, Zvi. 1988. Productivity Puzzles and R&D: Another Nonexplanation. *Journal of Economic Perspectives* 2,4: 9-21.

Griliches, Zvi. 1994. Productivity, R&D, and the Data Constraint. *American Economic Review* 84,1: 1-23.

Grubb, W. Norton. 1982. The Dynamic Implications of the Tiebout Model: The Changing Composition of Boston Communities, 1960-1970. *Public Finance Quarterly* 10: 17-38.

Holtz-Eakin, Douglas. 1993a. New Federal Spending for Infrastructure: Should We Let This Genie Out of the Bottle? In *Public Infrastructure Investment: A Bridge to Productivity Growth?* Public Policy Brief Number 4. The Jerome Levy Economics Institute of Bard College.

Holtz-Eakin, Douglas. 1993b. State-specific estimates of state and local government capital. *Regional Science and Urban Economics* 23: 185-209.

Holtz-Eakin, Douglas. 1993c. Why a Federal Plan Isn't Needed. *Spectrum -- The Journal of State Government* 66,4: 35-44.

Holtz-Eakin, Douglas. 1994. Public-Sector Capital and the Productivity Puzzle. *Review of Economics and Statistics* 76,1: 12-21.

Holtz-Eakin, Douglas and Amy Ellen Schwartz. 1995a. Infrastructure in a Structural Model of Economic Growth. *Regional Science and Urban Economics* 25: 131-151.

Holtz-Eakin, Douglas and Amy Ellen Schwartz. 1995b. Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways. *International Tax and Public Finance*, forthcoming.

Hulten, Charles R. and Robert M. Schwab. 1984. Regional Productivity Growth in U.S. Manufacturing: 1951-78. *American Economic Review* 74,1: 152-162.

Hulten, Charles R. and Robert M. Schwab. 1991. Public Capital Formation and the Growth of Regional Manufacturing Industries. *National Tax Journal* 44: 121-134.

Jorgenson, Dale W. 1991. Fragile Statistical Foundations: The Macroeconomics of Public Infrastructure Investment. Conference Paper, American Enterprise Institute, February, 1991.

Kain, John. 1990. Deception in Dallas: Strategic Misrepresentations in Rail Transit Promotion and Evaluation. *Journal of the American Planning Association* 56,2: 184-196.

Kaplan, Marshall. 1990. Infrastructure Policy: Repetitive Studies, Uneven Responses, Next Steps. *Urban Affairs Quarterly* 25,3: 371-388.

Keeler, Theodore E. and Kenneth A. Small. 1977. Optimal Peak Load Pricing, Investment, and Service Levels on Urban Expressways. *Journal of Political Economy* 85: 1-25.

Kelejian, Harry H. and Dennis P. Robinson. 1994. Infrastructure Productivity: A Razor's Edge. Working Paper, University of Maryland.

Kessides, Christine. 1993. The Contributions of Infrastructure to Economic Development: A Review of Experience and Policy Implications. World Bank Discussion Paper. Washington, D.C.

Krugman, Paul. 1990. *The Age of Diminished Expectations: U.S. Economic Policy in the 1990s*. Cambridge, Massachusetts: The MIT Press.

Krugman, Paul. 1994. *Peddling Prosperity: Economic Sense and Nonsense in the Age of Diminished Expectations*. New York: W.W. Norton & Company.

Lerner, Andrew C. 1992. We Cannot Afford Not to Have a National Infrastructure Policy. *Journal of the American Planning Association* 58,3: 362-367.

Luce, Thomas F., Jr. 1994. Local Taxes, Public Services, and the Intrametropolitan Location of Firms and Households. *Public Finance Quarterly* 22,2: 139-167.

Mohring, Herbert. 1961. Land Values and the Measurement of Highway Benefits. *Journal of Political Economy* 79: 236-249.

Mohring, Herbert and Mitchell Harwitz. 1962. *Highway Benefits: An Analytical Framework*. Evanston, Illinois: Northwestern University Press.

Munnell, Alicia H. 1990a. How Does Infrastructure Affect Regional Economic Performance? In *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Proceedings of Federal Reserve Bank of Boston conference, June 1990.

Munnell, Alicia H. 1990b. Why Has Productivity Growth Declined? Productivity and Public Investment. *New England Economic Review*. January/February 1990, 3-22.

Munnell, Alicia H. 1992. Policy Watch: Infrastructure Investment and Economic Growth. *Journal of Economic Perspectives* 6,4: 189-198.

Nathan, Richard P. 1992. Needed: A Marshall Plan for Ourselves. In *Exploring Urban America: An Introductory Reader*, Roger W. Caves, ed. Thousand Oaks, California: Sage Publications.

Netzer, Dick. 1992. Do We Really Need a National Infrastructure Policy? *Journal of the American Planning Association* 58,2: 139-143.

Payne-Maxie Consultants and Blaney-Dyett, Urban and Regional Planners. 1980. *The Land Use and Urban Development Impacts of Beltways*. Final Report DOT-OS-90079 for the U.S. Department of Transportation and U.S. Department of Housing. Washington, D.C.: U.S. Government Printing Office.

Pickrell, Donald H. 1992. A Desire Named Streetcar -- Fantasy and Fact in Rail Transit Planning. *Journal of the American Planning Association* 58,2: 158-176.

Pindyck, Robert S. and Daniel L. Rubinfeld. 1992. *Microeconomics* Second Edition. New York: Macmillan Publishing Company.

Rephann, Terance and Andrew Isserman. 1994. New Highways as Economic Development Tools: An Evaluation Using Quasi-Experimental Matching Methods. *Regional Science and Urban Economics* 24: 723-751.

Seskin, Samuel N. 1990. Comprehensive Framework for Highway Economic Impact Assessment: Methods and Results. *Transportation Research Record* number 1274.

Sims, Christopher A. 1972. Money, Income, and Causality. *American Economic Review* 62: 540-552.

Small, Kenneth A. 1983. The Incidence of Congestion Tolls on Urban Highways. *Journal of Urban Economics* 13: 90-111.

Small, Kenneth A. 1993. Congestion Pricing: New Life for an Old Idea? *Access*. Number 2, Spring, 1993. Berkeley, California: University of California Transportation Center.

Small, Kenneth A., Clifford Winston and Carol A. Evans. 1989. *Road Work: A New Highway Pricing & Investment Policy*. Washington, D.C.: The Brookings Institution.

Stephanedes, Yorgos J., and Eagle, David. 1987. Highway Impacts on Regional Employment. *Journal of Advanced Transportation* 21: 67-79.

Stephanedes, Yorgos J. 1990. Distributional Effects of State Highway Investment on Local and Regional Development. *Transportation Research Record* number 1274, 156-164.

Tatom, John A. 1991. Public Capital and Private Sector Performance. *St. Louis Federal Reserve Bank Review* 73,3: 3-15.

U.S. Department of Transportation. 1992a. *Assessing the Relationship Between Transportation Infrastructure and Productivity*. Policy Discussion Series number 4. Washington, D.C.: U.S. Department of Transportation.

U.S. Department of Transportation. 1992b. *Exploring Key Issues in Public-Private Partnerships for Highway Development*. Policy Discussion Series, Number 2. Washington, D.C.: U.S. Department of Transportation.

Vickrey, William S. 1963. Pricing in Urban and Suburban Transport. *American Economic Review* 53: 452-465.

Wachs, Martin. 1994. Will Congestion Pricing Ever Be Adopted? *Access.* Number 4, Spring 1994. Berkeley, California: University of California Transportation Center.

Weisbrod, Glen E. and James Beckwith. 1992. Development Benefits for Highway Decision-Making: The Wisconsin Case. *Transportation Quarterly* 46,1: 57-79.

Weisskopf, Thomas E., Samuel Bowles and David M. Gordon. 1983. Hearts and Minds: A Social Model of U.S. Productivity Growth. *Brookings Papers on Economic Activity* 14: 381-441.

White, Michelle J. 1976. Firm Suburbanization and Urban Subcenters. *Journal of Urban Economics* 3: 323-343.

Wieand, Kenneth F. 1987. An Extension of the Monocentric Urban Spatial Equilibrium Model to a Multicenter Setting: The Case of the Two-Center City. *Journal of Urban Economics* 21: 259-271.

Winston, Clifford M. 1990. How Efficient is Current Infrastructure Spending and Pricing? In *Is There a Shortfall in Public Capital Investment?*, Alicia H. Munnell, ed. Proceedings of Federal Reserve Bank of Boston conference, June 1990.

Yinger, John. 1993. Around the Block: Urban Models with a Street Grid. *Journal of Urban Economics* 33: 305-330.