Public Infrastructure Investments, Productivity and Welfare in Fixed Geographic Areas

Andrew F. Haughwout
Federal Reserve Bank of New York
Andrew.Haughwout@ny.frb.org

Abstract

Measures of the value of public investments are critical inputs into the policy process, and aggregate production and cost functions have become the dominant methods of evaluating these benefits. This paper examines the limitations of these approaches in light of applied production and spatial equilibrium theories. A spatial general equilibrium model of an economy with nontraded, localized public goods like infrastructure is proposed, and a method for identifying the role of public capital in firm production and household preferences is derived. Empirical evidence from a sample of large US cities suggests that while public capital provides significant productivity and consumption benefits, an ambitious program of locally funded infrastructure provision would likely generate negative net benefits for these cities.

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I. The debate over infrastructure

While the value of public capital has been a subject of substantial controversy, recent research has primarily focused on only one component of infrastructure's effect. But the nation's infrastructure investment has many dimensions. Among these are the consumption value of public capital, its productivity, and its role in influencing the location of economic activity. This paper addresses these dimensions simultaneously by providing both a new method and a new data set for estimating infrastructure benefits.

Public capital may influence social welfare in two ways. The first is through income. If infrastructure contributes positively to private productivity, then more infrastructure will raise incomes and increase welfare. Concern about the role of public investment policies in productivity growth has generated many recent studies attempting to explore the role of infrastructure in private production, particularly since Aschauer (1989) used national time series data to estimate an astonishingly high marginal productivity for public capital.

While the marginal productivity of public capital is certainly one component of its aggregate social value, many of the most prominent authors in the ongoing debate over infrastructure productivity have recognized that direct, non-pecuniary, household benefits are a second avenue by which infrastructure may affect welfare. The direct consumption benefits of public capital have been a less direct focus of current scholarship, even though findings of zero productivity do not by themselves lead to the conclusion that infrastructure is efficiently supplied. Instead, reliable results from productivity and household studies must be combined with cost information to answer the normative question of whether the nation would benefit by directing more of its resources to public investment. This paper explores the limitations in current approaches to estimating infrastructure's contribution to productivity and provides a new strategy for analyzing the value of public capital in production and consumption. The alternative described here provides a fuller and more theoretically consistent accounting of these benefits, and allows clearer insight into the normative issues involved in infrastructure decision making.

Aschauer's study opened a veritable growth industry in infrastructure research, much of which utilized the aggregate production, or the analogous aggregate cost function, approaches. The problems inherent in satisfactory estimation of relationships among short, non-stationary time series (Aaron 1990, Hulten and Schwab 1991) quickly led researchers to explore the substantial interregional variation in public capital provision *within* the US. The interregional approach offers substantial increases in degrees of freedom and thus an opportunity to exploit more sophisticated statistical methods. Further, the majority of the nation's non-military public capital stock is owned by state and local governments (Haughwout and Inman 1996, Holtz-Eakin 1994), and those governments are likely to invest in systems that generate benefits concentrated within their own borders. State/local analyses implicitly recognize that public investments serve limited geographic areas, and it is likely that the output responses they induce would be concentrated within these service areas.

Munnell (1990) and Eberts (1990) applied the aggregate production function (APF) approach to panels of states and metropolitan areas, respectively. Each found significantly positive output responses, although the implied output elasticities were far lower than Aschauer's original estimates. Nonetheless, Munnell's estimated state-level output elasticity of 0.15 was large enough to provoke continued interest in the possibility of unexploited returns to public investment. More recent refinements to the aggregate production approach have focused thoroughly on the model's statistical properties. In Holtz-Eakin (1994) and Garcia-Mila, McGuire and Porter (1996), correction of the estimates for unobserved state-level characteristics reduces the elasticity of public sector capital to zero, suggesting that the findings of Munnell (1990) resulted from correlations between infrastructure and unmeasured state traits.

In a parallel set of papers, several authors have applied aggregate cost functions (ACFs) to data sets similar to those used for analysis of aggregate production functions. In the ACF approach, the marginal productivity of public capital is measured by calculating its role in reducing private production costs. This is accomplished by estimating the reductions in aggregate private input utilization that additional public infrastructure allows. ACF estimates have generally been more favorable than recent APF results to the argument that there is a positive role for public capital in production. Berndt and Hansson (1992) report that public capital is a significant cost-reducing factor in a study of the Swedish economy, while Nadiri and Mamuneas (1994) find the same for twelve U.S. manufacturing industries at the national level. Finally, in a paper particularly relevant to the current discussion, Morrison and Schwartz (1996) report that application of the aggregate cost approach to a panel of American states reveals a significant role for infrastructure in reducing private production costs, even when unmeasured state factors are controlled. This result appears to conflict directly with the findings of Holtz-Eakin (1994) and Garcia-Mila, McGuire and Porter (1996), who argued that after controlling for unmeasured state effects the marginal productivity of public capital is indistinguishable from zero.

The distinction between the APF and ACF approaches to the estimation of factor productivities is based on contrasting theories of what may be treated as exogenous to firms (Friedlander 1990, Berndt 1991). Advocates of aggregate production functions implicitly argue that productive inputs (employment, private capital stock, etc.) are exogenously determined, and firms make output decisions based on the availability of these factors. Under this hypothesis, the question of infrastructure productivity becomes whether additions to public capital stocks increase the output that can be obtained from given input stocks. In practice, this is equivalent to the assumption that disturbances in output will be uncorrelated with quantities of inputs available.

ACF authors, however, prefer the assumption that input *prices*, not quantities, are treated as exogenous by producers. Morrison and Schwartz (1996) concur with Berndt (1991) in suggesting that ACF estimates are thus free of endogenous variable bias that plagues production function estimation, an argument that has a long history in the applied production theory literature. In this literature, authors have emphasized that while input use is clearly endogenous to production decisions, input prices will, in a competitive economy, be exogenous to the decisions of any particular firm.[1] The ACF and APF approaches thus embody opposite assumptions about own-price factor supply elasticities. Perfectly inelastic factor supply schedules (quantities given) suggest the APF approach, while perfect elasticity (prices given) suggests that ACF is the

[1]Both Diewert (1974) and McFadden (1978) contain useful surveys and original contributions. This point was originally made in the context of infrastructure productivity estimation by Friedlander (1990).

appropriate theoretical framework.

But application of this logic to the aggregate behavior of regions like the US states raises new issues. There are two sets of reasons to be concerned about the effects of aggregation. First is the question of whether the relationships among production aggregates can be interpreted. In a series of papers, Fisher (1968a, 1968b, 1969) studied the conditions for the existence of consistent relationships between aggregate and microeconomic functions and variables. His findings are discouraging to those who wish to analyze these measures. The conditions under which an aggregate production function exists, for example, are found to be quite restrictive, and even such variables as aggregate capital and labor stocks and aggregate output will be meaningful only in very special circumstances. Fisher (1969) acknowledges that contemporary national time series estimates of such aggregate production functions performed surprisingly well, generally providing output elasticity estimates for labor and private capital near their shares in total income. He attributes this success to the fact that relative input stocks and prices had not changed dramatically over the years for which data were available. But if the reliability of estimated aggregate relationships depends on the stability of relative factor prices and/or quantities, then the estimates retrieved from aggregated estimating equations would presumably become less reliable as this stability breaks down. And the stylized fact that relative input prices and quantities are stable at the national level over time does not necessarily imply that they will be consistent over time and regions *within the nation*. Indeed, there is substantial variation across the states in both input stocks (see, for example, the data in Morrison and Schwartz 1996 and in Holtz-Eakin 1992) and prices over the post-WWII period (Carlino and Mills 1996). Aggregate production function estimates have been especially plagued by implausible estimates of the marginal productivities of private inputs (Berndt and Hansson 1992).

Additional to these problems with the interpretation of aggregate variables and relationships is a second, related, set of issues. While the hypothesis of price exogeneity may be appropriate for the analysis of individual competitive firms, it is a far less satisfactory description of regional behavior. Regions like the US states and *ex ante* defined metropolitan areas have complex factor markets in which both the pure price- and quantity-taking assumptions are likely to fail. Instead, an approach that acknowledges the realities of regional factor markets may be more appropriate.

Since the geographic areas defined as regions (states or federally-defined metropolitan areas) are pre-determined, their land area represents a fixed factor with an endogenous price which varies over space. Meanwhile, private capital supply to small regions is perfectly elastic at a nationally-determined (exogenous) price, but labor supply is neither perfectly elastic nor inelastic, and both wages and labor supply are endogenous to regions. The compensating variations literature pioneered by Rosen (1979) and Roback (1982), and extended by Blomquist, Berger and Hoehn (1988) shows that when regions are profit and utility takers, the value of unpriced, nontraded regional traits like climate or infrastructure stock will be fully reflected in local factor prices. Ultimately, maintained hypotheses about what is exogenous to regions are crucial, as they determine whether factor prices, quantities, or neither can be treated as exogenous explanatory variables in regional analysis.

Neither of the dominant methods of analyzing infrastructure productivity controls for the possibility that regional factor prices reflect part of the value of public capital. But if households and firms are mobile across regions, then wages and land values will vary in response to infrastructure provision, and the ACF and APF approaches can not adequately estimate the marginal productivity of public capital, let alone its social value. Exploiting regional data to answer the nation's infrastructure questions requires an empirical method which utilizes plausibly exogenous variables to identify the dual roles of public capital in firm production technologies and household consumption. Spatial equilibrium theory provides such a method. Section II derives and motivates an alternative measure of infrastructure's social value based on spatial equilibrium, and comments on its implications for aggregate approaches. Section III provides estimates of the role of public infrastructure in production and consumption in a set of US cities and Section IV interprets the results and concludes the paper.

II. Model

Following the compensating variations literature pioneered by Rosen (1979) and Roback (1982), assume that regions are profit rate and utility takers. Like the maintained hypotheses of the APF and ACF approaches, this is a polar case, but one which is more consistent with both the concept of spatial equilibrium and the high degree of mobility exhibited by residential and business activities in the US.

Workers and firms compete for scarce sites across regions. Individual firms produce a composite output good using a production technology of the form $x_j = x\{G_j, n_j, m_j\}$, where x is firm production, G is infrastructure available, n is private employment, m is land used by firms, and *j* indexes regions.[2] For simplicity, assume that the firm's technology exhibits constant

[2]The exclusion of private capital has no effect on the regional economic equilibrium, as long as it is freely mobile and its price is determined in national markets, as is assumed here.

returns across the private inputs n and m.[3] Local input demands per unit of output (referred to as $n_j^1(R_j, W_j, G_j)$ and $m_j^1(R_j, W_j, G_j)$) will depend on regional prices for land (*R)* and labor (*W*) and infrastructure stocks. The zero-profit equilibrium condition for a firm in the *j*th region is

$$(1) \quad c\{W_j, R_j, G_j\} = P_X$$

then

where $c\{\bullet\}$ is the firm's unit cost function and P_x is the price of the composite output good which is determined in national or world markets. The *j*th region's public capital stock is "productive" to an individual firm if $\frac{\partial x}{\partial G_j} = mpg_j > 0$, or, equivalently, if $\frac{\partial c}{\partial G_j} < 0$.

A finding that infrastructure is productive in this sense could be important in models of economic growth. Aschauer (1989), for example, argues that a decline in relative infrastructure spending was an important contributor to the US productivity growth slowdown that began in the 1970s, while Munnell (1990, 1992) endorses this position and suggests that

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[3]Violation of this assumption complicates the analysis but does not weaken the argument against the aggregative approach.

infrastructure differentials help explain interregional productivity variations. But as noted above, infrastructure's contribution to productivity is only one component of its social value.

The empirical literature has treated infrastructure as a pure national (Aschauer 1989), state (Holtz-Eakin 1994, Morrison and Schwartz 1996) or regional (Eberts 1990) public good. The aggregate marginal productivity of infrastructure may then be calculated by summing the individual productivity benefits across firms, $MPG_j = \Sigma \frac{\partial x}{\partial G_j}$ where the summation is over all firms in the region. The ideal method of analysis of the aggregate role of infrastructure in production is thus to collect data on individual firms, calculate the marginal productivity of infrastructure for each, and aggregate these individual productivities to reflect infrastructure's nature as a public good. In practice, sufficient data on the behavior of individual firms are unavailable, and researchers have turned to the analysis of aggregate outcomes. It is crucial to recognize, however, that the question of infrastructure's productivity is a question about its effects on the output of individual firms, not on aggregate output. Cross-sectional or panel data evidence that infrastructure is associated with higher aggregate output at the regional level does not necessarily mean that increasing infrastructure stocks will raise *national* output, since the increase in productivity may be entirely associated with relocations of productive factors from other regions (Haughwout 1998).

The potential for mobility of productive inputs means that even when the productivity of public capital is the only question of interest, a model of household behavior is necessary if aggregate data are to be analyzed. Assume that individual households have well-behaved[4] utility

[4]Twice-differentiable, quasi-concave.

functions of the form $u_j = u(x_j, l_j, G_j)$, where x and l are, respectively, the household's consumption of the composite good and land, and j again indexes locations. Households maximize utility subject to the constraint that their expenditures equal the wage income they earn by (inelastically) supplying one unit of labor in the local productive process. In a free-mobility equilibrium, the level of indirect utility achievable by a household is identical across locations, or $u_j(\bullet) = \overline{V}$, where $\overline{V}$ is the nationally determined equilibrium utility level. Thus, the household must receive a wage (W_j) that, given local land price R_j and infrastructure stock G_j, enables it

$$(2) \quad W_j = e(R_j, G_j, P_X, \overline{V}).$$

to achieve the utility level which it can attain elsewhere:[5]

[5]The household's (constant utility) wage bid function is an expenditure function, as the notation indicates.

Public capital G is directly valuable as a consumption good if and only if $\frac{\partial u}{\partial G_j} > 0$ or, equivalently, if $\frac{\partial e}{\partial G_j} < 0$.

Following Roback (1982), firm and household equilibrium conditions (1) and (2) may be

$$(3) \quad R_j^* = R(P_X, G_j, \overline{V});$$

$$(4) \quad W_j^* = W(P_X, G_j, \overline{V}).$$

implicitly solved for equilibrium local prices W_j^* and R_j^*:

Since both P_X and $\overline{V}$ are exogenous to any small region, local prices will vary with local infrastructure stocks, the only unpriced, locationally fixed argument of either household or firm behavior (Roback 1982).[6]

[6] In practice, of course, other non-traded public goods and amenities (like taxes and climate) will affect local prices. See, *inter alia*, Roback (1982), Blomquist, Berger and Hoehn (1988), Gyourko and Tracy (1991). The current framework is general in that we can consider G_j a vector of non-traded goods. This is the treatment adopted in the empirical analysis below.

Aggregate Output, Employment and Land Use

Let $X^*_j = \sum x_j$, where the summation is over all firms in the region, represent aggregate output produced in region *j*. Under the assumption of constant returns over the private inputs at the firm level, expressions may be derived for aggregate employment, $N^*_j = n^1_j(\bullet) * X^*_j$, land use by firms, $M^*_j = m^1_j(\bullet) * X^*_j$ and land use by households $L^*_j = l_j(\bullet) * N^*_j = l_j(\bullet) * n^1_j(\bullet) * X^*_j$. For the land market in region *j* to clear, its available land area $\overline{L}_j$ must be exhausted by firm and household demands.[7] Thus, $M^*_j + L^*_j = (m^1_j + l_j * n^1_j)\, X^*_j = \overline{L}_j$, where, as above, m^1_j and n^1_j are firm demands for land and labor per unit output, l_j is demand for land by each household, and X^*_j is aggregate output produced in the region. Equilibrium aggregate output produced in region *j* is then given by

$$(5) \quad X^*_j = \frac{\overline{L}_j}{(m^1_j + l_j * n^1_j)} = \frac{\overline{L}_j}{L^1_j(R^*_j, W^*_j, G_j)}$$

where $L^1_j = m^1_j + l_j * n^1_j$ is the total land area utilized by firms and households in the production of each unit of output.

[7]The assumption of fixed area is consistent with the analysis of states and other areas of fixed geography, like metropolitan areas defined ex ante by the federal government. Of course, the appropriate geographic scale for the analysis infrastructure benefits is a crucial question. It is plausible that infrastructure generates costs and benefits that spill over political jurisdictions' boundaries and that regional definitions are themselves endogenous. Evidence on this point is found in Boarnet (1997) and Haughwout (1997, 1999).

Comparative Statics

Differentiation of (5) reveals the importance of local price adjustment in determining the effects

$$(6)\quad \frac{dX_j^*}{dG_j} = \frac{-X_j^*}{L_j^1}[k_W \frac{dW_j^*}{dG_j} + k_R \frac{dR_j^*}{dG_j} + k_G]$$

of infrastructure on aggregate output

where $k_W = \frac{\partial m_j^1}{\partial W_j^*} + l_j \frac{\partial n_j^1}{\partial W_j^*} + n_j^1 \frac{\partial l_j}{\partial W_j^*}$, $k_R = \frac{\partial m_j^1}{\partial R_j^*} + l_j \frac{\partial n_j^1}{\partial R_j^*} + n_j^1 \frac{\partial l_j}{\partial R_j^*}$ and

$$k_G = \frac{\partial m_j^1}{\partial G_j} + l_j \frac{\partial n_j^1}{\partial G_j} + n_j^1 \frac{\partial l_j}{\partial G_j}.$$

Further, employing Shephard’s lemma, it is possible to show that

$$(7)\quad \frac{dR_j^*}{dG_j} = \frac{-1}{L_j^1}[\frac{\partial c}{\partial G_j} + n_j^1 \frac{\partial e}{\partial G_j}] \quad \text{and}$$

$$(8)\quad \frac{dW_j^*}{dG_j} = \frac{1}{L_j^1}[m_j^1 \frac{\partial e}{\partial G_j} - l_j \frac{\partial c}{\partial G_j}]$$

Inspection of (7) and (8) provides insights into the equilibrium effects of public investment. When infrastructure is valuable to *both* households and firms, both $\frac{\partial c}{\partial G_j}$ and $\frac{\partial e}{\partial G_j}$

are negative. In these circumstances, $\frac{dR_j^*}{dG_j} > 0$, but equilibrium wages may rise or fall, depending on which sector (firms or households) benefits more from the investment. If infrastructure is productive but does not directly affect households, then $\frac{\partial c}{\partial G_j} < 0$, $\frac{\partial e}{\partial G_j} = 0$, and both land and labor price effects are positive.

But the sign of $\frac{dX_j^*}{dG_j}$ is indeterminate, even when households are indifferent to infrastructure and infrastructure plays a positive role in the production functions of every individual firm.[8] A finding that $\frac{dX_j^*}{dG_j} > 0$ is *not* evidence that infrastructure is productive, i.e., it does not indicate that $\frac{\partial c}{\partial G_j} < 0$. The role of market prices in compensating firms and households for the value of unpriced elements of the environment makes it impossible for analyses of aggregate output and factor demands to uncover the role of infrastructure in either production and consumption. Only analysis of local price effects can accomplish this goal. It is to this task that we now turn, after brief examinations of the aggregate social value of infrastructure and the identification of its separate impacts on households as producers and consumers.

Willingness to pay for infrastructure and measuring public capital's value to firms and

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[8] Substitution of (7) and (8) into (6) yields a complex expression for the relationship between aggregate output and infrastructure provision.There is no regular relationship between a productive public good and aggregate output. See Haughwout (1998) for more detail and discussion.

households

In addition to providing a more theoretically consistent empirical model of infrastructure impacts, the compensating variations method allows both calculation of the aggregate social value of public capital investments and identification of the two avenues by which it affects welfare.

Private actors' evaluations of infrastructure are expressed as their willingness to pay for additional infrastructure, ceteris paribus. For individual firms, this is $-\frac{\partial c}{\partial G_j}$ (constant-profit cost savings per unit output), while for households it is $-\frac{\partial e}{\partial G_j}$ (constant-utility expenditure savings per household). Aggregate social value is then equivalent to aggregate willingness to pay[9]:

[9]Roback (1982) obtains an identical result, but does not apply it to the analysis of public decision-making.

$$SV_j = - X^*_j \frac{\partial c}{\partial G_j} - N^*_j \frac{\partial e}{\partial G_j} = - X^*_j \{ - (n^1_j \frac{dW^*_j}{dG_j} + m^1_j \frac{dR^*_j}{dG_j}) \} - N^*_j \{ \frac{dW^*_j}{dG_j} - l_j \frac{dR^*_j}{dG_j} \}$$

$$= (M^*_j + L^*_j) \frac{dR^*}{dG} = L_0 \frac{dR^*}{dG}$$

The question of whether there is “enough” infrastructure is thus whether aggregate willingness to pay for additional infrastructure equals its aggregate social costs. The efficiency rule is thus to continue investing in public capital as long as new (net) investment increases jurisdictional land prices (taxes constant). This rule bears no consistent relationship to the test implicit (and sometimes explicit) in the APF and ACF literature, which is to invest until aggregate marginal product equals social marginal tax cost, including excess burden (Morrison and Schwartz 1996). Indeed, it is clear from (6) that public decisions which attempt to maximize output or employment will not generally be allocatively efficient, at least from the point of view of the investing jurisdiction.

In spite of the fact that the sign and size of $\frac{dW^*_j}{d\,G_j}$ are irrelevant to the efficiency of local public sector activity, its estimation serves a valuable purpose. With it, we can determine the incidence of infrastructure benefits across the two sectors. This is crucial, since $\frac{dX^*_j}{dG_j} > 0$ cannot be interpreted as evidence that public good G is productive. But the compensating variations method allows identification of the separate effects of infrastructure on firm productivity and household welfare. Rearrangement of (7) and (8) yields

$$(9)\quad \frac{\partial c}{\partial G_j} = -\left(n_j^1 \frac{dW_j^*}{dG_j} + m_j^1 \frac{dR_j^*}{dG_j} \right)$$

and

$$(10)\quad \frac{\partial e}{\partial G_j} = \frac{dW_j^*}{dG_j} - l_j \frac{dR_j^*}{dG_j}$$

Under the assumption of free mobility, estimates of $\frac{dW_j^*}{dG_j}$ and $\frac{dR_j^*}{dG_j}$ can thus be combined with land use and employment data to separately identify household and firm willingness to pay for infrastructure (or other public services) located in a particular geographic area.

III. Data, estimation and evidence on the effects of city infrastructure

Calculation of infrastructure's effects on regional prices requires an empirical design which can distinguish infrastructure effects from those generated by other produced and non-produced regional traits. The dependent variables for the estimation are central city house prices and wages from the *American Housing Survey* national files micro data, while the principal independent variables are constructed from US Bureau of the Census' *Government Finances* publication series. While the data set includes detailed information on houses and their residents that varies within cities in a given year, the fiscal information in a given year varies only across, not within, cities. A complete list of variables, the type of variation they provide and their sources appears in Table 1. Table 2 provides descriptive statistics for the key variables.

The public capital data differ in two key ways from those currently in widespread use. The replacement value of pubic capital in place is estimated by applying the perpetual inventory technique to gross-of-depreciation capital investment flows from the early part of this century to the present. Holtz-Eakin (1993) and Munnell (1990) both provide state-level estimates of the replacement value of public capital in place by apportioning national aggregates to each state based on the state's share of national gross investment during a benchmark period. This procedure introduces the possibility of systematic measurement error into the public capital measure, since investments made during the benchmark period may be correlated with factors other than historical investment patterns. Because the current method requires no bench marking, it provides a measure of city and state public capital that is less likely to contain measurement error.[10] Haughwout and Inman (1996) contains a complete description of the public capital data and 1972-1992 values for each of the central cities analyzed here.

The infrastructure measure employed here requires data on the investments made by each government over a long historical period, and such data are available only for state governments and large cities. While the analysis is thus limited to the effects of infrastructure provision in the cities listed in Table 3, the addition of sub-state infrastructure variation into the analysis is valuable. Recent evidence suggests that infrastructure investments have effects on the intra-state location of economic activities. Boarnet (1997) finds that investments in highway infrastructure in California counties draw activity from other parts of the state, while Haughwout (1997, 1999)

[10]Garcia-Mila, McGuire and Porter (1996), using an aggregate production function model, test for and reject the hypothesis that the Munnell series is measured with error.

finds that city infrastructure investments increase both city and suburban land values. In Gyourko, Haughwout and Inman (1997) and Haughwout (1999) state infrastructure investments are found to reduce city and suburban land values, respectively. Taken together, these results imply that infrastructure investments have important effects on the intra-state distribution of activities. If this conclusion is correct, then the case for state-level analysis is considerably weakened. It also qualifies the interpretation of the empirical analysis performed here. If infrastructure is found to have a positive marginal benefit in these central cities, it does not follow that it has positive effects in the state as a whole. Benefits realized in the city jurisdiction may come at the expense of other areas of the state (as in Boarnet 1996), and/or may spill over to spatially proximate jurisdictions (Haughwout 1997, 1999).

A two-stage estimation procedure is performed to determine whether city infrastructure can account for the any of the variance in land prices and wages across metropolitan areas over time. In the first stage, city-specific effects in land prices and wages over time are computed. Determining them requires estimation of land price and wage equations:

$$(11)\quad \text{Log}\, HV_{i,j,t} = \alpha_1 HQ_{i,j,t} + \alpha_2 C_j \bullet T_t + \varepsilon_{i,j,t}$$

$$(12)\quad \text{Log}\, W_{i,j,t} = \beta_1 HC_{i,j,t} + \beta_2 C_j \bullet T_t + \mu_{i,j,t}$$

Here, i, j, and t respectively index individuals, metropolitan areas and time, HV is house value, W is the household head's wage, and HQ and HC are vectors of house quality and human capital controls. C_j and T_t are, respectively, city and time dummy variables; their interaction allows estimation of city-year specific effects in house prices and wages. $\varepsilon_{i,j,t}$ and $\mu_{i,j,t}$ are standard "white noise" residual terms. These first-stage regressions are estimated with ordinary least squares over 37,503 households in 33 central cities in 12 cross sections. A list of the cities, the years they are present in the data set and their mean values for $\hat{\alpha}_2$ and $\hat{\beta}_2$ are provided in Table 3.

The second stage of the estimation strategy involves examining whether variance in local amenities (A_j), local or state current tax/service conditions ($LTS_{j,t}$ and $STS_{j,t}$), and public infrastructure conditions ($LG_{j,t}$ and $SG_{j,t}$) can account for the variance in the estimated city-specific effects over time in local prices. The $\hat{\alpha}_2$ and $\hat{\beta}_2$ vectors (each a 355x1 column vector) from equations (11) and (12) are then regressed on the city-specific variables:

$$(13) \quad \hat{\alpha}_{2,j,t} = \alpha_4 A_j + \alpha_5 LTS_{j,t} + \alpha_6 STS_{j,t} + \alpha_7 LG_{j,t} + \alpha_8 SG_{j,t} + \alpha_9 \hat{\beta}_{2,j,t} + \nu_{j,t}$$

$$(14) \quad \hat{\beta}_{2,j,t} = \beta_4 A_j + \beta_5 LTS_{j,t} + \beta_6 STS_{j,t} + \beta_7 LG_{j,t} + \beta_8 SG_{j,t} + \beta_9 \hat{\alpha}_{2,j,t} + \eta_{j,t}$$

The coefficients α_7 and β_7 retrieved from simultaneous equations estimation of these structural equations are the estimated land price and wage effects of central city infrastructure stocks, which are the basis of the willingness to pay calculations provided below.

City land area and city infrastructure specification

Two further estimation issues arise. First, standard urban economic models emphasize the importance of proximity to employment nodes in determining the market value of land, with centrally located properties commanding the highest locational premia (Fujita, 1989). In the present context, it is thus likely that physical size of the central city will have a ceteris paribus effect on the city-specific land price effect, since the sample of houses drawn from a geographically larger city will be more heavily weighted toward units that are relatively distant from the central business district. Addition of city land area to the second stage regressions controls for this element of the *AHS* sampling design.

A more substantive question that has received little attention in aggregate models is the congestibility of physical infrastructure. In the majority of recent APF and ACF studies, infrastructure is measured as the replacement value of the current stock and is treated as a pure, uncongestible public good. Of course, the true value of infrastructure is the services it provides, and these services may be (inversely) related to the population utilizing the facility. Here, we perform a grid search for the proper specification by substituting

$LG_{j,t} = f(STOCK_{j,t}) = \frac{STOCK_{j,t}}{POP_{j,t}^{\gamma}}$, where γ ranges from 0 (a pure public good specification) to 1 (pure private good).

The grid search reveals that the effect of infrastructure on city land premia falls monotonically as γ rises. Measured as a pure private good $(\gamma = 1)$, infrastructure has an insignificantly negative effect on land values (and, as is the case for all other values of γ, no significant effect on wages). As γ falls, the infrastructure coefficient becomes significantly positive. These effects are driven by the presence of city population in the denominators of the infrastructure measures. When city population is included as a separate regressor, its coefficient estimate is strongly positive and statistically significant and the coefficient on infrastructure stock per capita (i.e., $\gamma = 1$) becomes positive and significant. Under the compensating variations framework, city populations (like city employment) are endogenous, responding to city land and labor market conditions rather than the converse. These considerations, along with the fact that the specification with $\gamma = 0$ describes the data best (i.e., it has the lowest mean squared error), confirm the treatment of infrastructure as uncongestible. This may seem surprising until it is recognized that the majority of the central cities in the sample have lost population since the 1960s. This suggests the potential for excess capacity in city infrastructure stocks, indicating that aggregate returns to new investments may be low, a judgement that is supported by the analysis below.

Effects of city public capital on regional factor prices

Table 4 reports the estimated city infrastructure elasticities retrieved from estimation of various specifications of equations (13) and (14). The specifications are distinguished by the assumptions about the linearity of infrastructure's effects on factor prices and by the treatment of the residual terms $\nu_{j,t}$ and $\eta_{j,t}$. Specifications 1 and 2 are estimated by three-stage least squares in order to control for simultaneity in local prices.[11] Identification is achieved by omitting city land area from the wage equation and city crime rates from the land price relationship. The latter restriction is supported by evidence that crime is perceived as a neighborhood phenomenon.[12] In

[11]The estimated city-year effects in wages and land prices are significantly positively correlated (r = 0.27).

[12] In post-1985 American Housing Surveys, question 50(a) reads: "How would you rate

these estimates, infrastructure has a significantly positive effect on city land prices, but wage effects are indistinguishable from zero.

In specifications 3 and 4 of Table 4, controls for simultaneity in prices are replaced with a two-way variance components estimator (feasible generalized least squares) for city land price premia. The specification test provided by Hausman (1978) provides little evidence of misspecification in the variance components estimator, in contrast to similar tests conducted on the aggregate state production function specification (Garcia-Mila et al, 1996). In these results, the estimated effect of city infrastructure on land prices is somewhat less precise. Without the wage equation, the estimates identify only the aggregate social value of infrastructure, but not its

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the neighborhood on a scale of 1 to 10? 10 is best, 1 is worst." Question 50(b) asks for the neighborhood's specific problems to be described, including problems with crime, traffic, and city or county public services. In Gyourko, Haughwout and Inman (1997), the authors find that removing neighborhood quality controls from the first stage regression results in a significantly negative coefficient on the crime variable in the second stage land price equation, which supports this hypothesis. Other identification restrictions do not significantly alter the results presented here.

components.

Recall from the spatial equilibrium theory described above that were infrastructure a purely productive input, we would anticipate positive land price and wage effects. Here, the evidence is that infrastructure provides benefits to both the firm and household sectors. It is also apparent that the dominant aggregative approaches to infrastructure benefits abstract from potentially informative covariation between infrastructure provision and local relative prices. The importance of these relationships emphasizes the role of nontraded public capital investments in affecting not only the level, but also the *spatial distribution* of productive and residential activities.

Results for other second stage variables[13]

Other second stage variables perform largely as expected. Our climatological and locational amenity measures are statistically significant and of the expected sign. As anticipated, the coefficient estimate on land area is negative and significant in the land price equation and insignificant in the wage equation. Local taxes are negatively capitalized into land prices at rates near 100%.

The effects of state policy measures are instructive. In spite of the attention paid to interregional mobility, intrastate migration dominates American residential relocations. During

[13] Details available upon request.

the 1980's and early 1990's, between 80 and 90 percent of residential relocations were within the same state. What this suggests for the current model is that local and state fiscal policies may well have substantially different effects. For example, while high city taxes may reduce the attractiveness of a city location, high state taxes may not, particularly if an active state government finances some services that other cities must fund from their own tax bases. In such cases, higher state taxes will lead to higher city land values, as we consistently find here. State infrastructure stocks have little effect on city land values or wages, as would be expected given that central cities are relatively small proportions of the states' total area. These findings underline the importance of careful attention to locational decision making in evaluating the effects of state and local fiscal policies. Models which combine the state and local sectors into single measures abstract from informative intra-state movements that they differentially induce.

Estimated willingness to pay for central city infrastructure

Producers' willingness to pay (WTP) for city infrastructure per unit output is calculated from equation (9) as $\frac{\partial c}{\partial G_j} = -(n_j^1 \frac{dW_j^*}{dG_j} + m_j^1 \frac{dR_j^*}{dG_j})$, while for a typical household, WTP is $\frac{\partial e}{\partial G_j} = \frac{dW_j^*}{dG_j} - l_j \frac{dR_j^*}{dG_j}$. The central city benefit generated by a one standard deviation (4.64 billion constant dollars) increase in mean city infrastructure stock is estimated as $L_0 \frac{dR^*}{dG}$.

Estimates of household and firm willingness to pay for infrastructure are presented in the second panel of Table 4.[14] Note that without the wage equation, the components of infrastructure's social value and its productivity are unidentified. While city infrastructure provision provides benefits at the margin, the social value of a one standard deviation increase in city infrastructure is not, for the typical city, sufficient to offset its cost. The largest aggregate value estimate (line 2 of Table 4) is just over 75% of the $4.64 billion cost required to raise infrastructure stock in the typical city by a sample standard deviation. It is also apparent that estimated household infrastructure benefits are substantial, probably exceeding firm benefits. Finally, the marginal productivity of infrastructure is estimated to be non-negative, but small.

IV. Conclusions

The model and empirical evidence presented here emphasize the importance of infrastructure investments in affecting the relative attractiveness of places, potentially redirecting growth from infrastructure-poor areas to those which have invested more heavily. While investments on the public agenda have evolved from canals and ports aimed at capturing the trade of unfinished agricultural products to fiber optic cable for providing internet bandwidth, part of the motivation for such investments has been the idea that they might provide some locations a competitive advantage vis a vis others (Pred 1966, Markoff 1997). But the implications of spatial competition among regions has not played a large role in dominant

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[14] These estimates use data from the *State of the Nation's Cities* data base (Center for Urban Policy Research, 1996).

approaches to modeling infrastructure impacts.

The spatial equilibrium approach adopted here emphasizes the importance of infrastructure in altering the distribution of economic activity across regions, and re-establishes the household sector to its joint roles as consumer of infrastructure services, supplier of labor and competitor in the land market. The model and empirical evidence suggest that central city land prices are, ceteris paribus, positively associated with infrastructure provision and that the benefits of a large public capital stock are likely enjoyed by both firms and households. A negative, statistically significant, firm cost elasticity of infrastructure is estimated. Nonetheless, substantial increases in city public infrastructure provision are unlikely to provide social benefits sufficient to offset their costs. On the other hand, it is likely that some of the benefits of city infrastructure investments spill over into neighboring suburban jurisdictions, suggesting that the estimates presented here may be a lower bound of the total value of such spending. In addition, from the point of view of the central city, it is quite likely that generous capital aid from other governments might make substantial capital investments worth their local cost (see Haughwout 1999 for a discussion).

This last observation points to a weakness of this paper and most of the current literature on public infrastructure impacts. While the empirical model assumes that infrastructure is exogenously determined, this is clearly not the case. Indeed, the current approach, in which infrastructure is envisioned as a contributor to local property values, underlines the complex relationship between the value of the local tax base and the level of infrastructure investment. It is clear that a more careful analysis of the determinants of public investment is indicated. Modeling public investment is complicated by the fact that public capital is only one, albeit generally the largest, component of a portfolio of public assets and liabilities (Haughwout and Inman 1996). The net local benefit generated by a program of long term borrowing to fund infrastructure investment is the crucial question faced by local decision makers and the municipal bond market (for preliminary evidence on this point, see Gyourko, Haughwout and Inman 1997). Until such a model is developed, however, it is crucial to develop methods of examining the impact of infrastructure on local areas that are based on a consistent theoretical underpinning. As demonstrated here, local price effects of public investments must play a prominent role in this effort.

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TABLE 1: Descriptions, Level of Variation and Sources for Key Variables

Dependent Variables: vary by house (i), region (j) and time (t). Source: American Housing Surveys, 1974-1991

1. HV House and land value, continuous.
2. W Annual wages and salaries, head of household, continuous.

HQ vector: House quality controls, vary by house (i), region (j) and time (t). Source: American Housing Surveys, 1974-1991

1. # of Bathrooms: Polychotomous, 1, 1.5, 2, 2.5+
2. # of Bedrooms: Polychotomous, 1, 2, 3, 4, 5, 6+
3. Basement: Dichotomous, 0-1
4. Condominium: Dichotomous, 0-1
5. Central Air Conditioning: Dichotomous, 0-1
6. Detached Unit: Dichotomous, 0-1
7. Garage Present: Dichotomous, 0-1
8. Age of House: continuous[15]
9. # of Other Rooms: continuous (=Total Rooms-Bedrooms-Bathrooms)
10. Public Sewerage Hookup: Dichotomous, 0-1
11. Heating Equipment: Polychotomous (Warm Air, Electric, Steam, Other)
12. House Quality Rating: Polychotomous (Excellent, Good, Fair, Poor)
13. Central City indicator: Dichotomous, 0-1

HC vector: Head of household human capital controls, vary by house (i), region (j), and time (t). Source: American Housing Surveys, 1974-1991

1. Age: continuous
2. Education: Polychotomous (No school, Elementary, Some HS, HS graduate, Some college, College graduate, Graduate school)
3. Married: Dichotomous, 0-1

[15]Age of the house is computed as a function of when the house is reported to have been built. Those data are reported in interval form. The midpoint of the interval is used as the year of construction. When bottom coding is relevant (for old homes), the house is assumed to have been built during the bottom code year.

4. White: Dichotomous, 0-1
5. Hispanic: Dichotomous, 0-1

Table 1, continued

STS and LTS: Local and State Tax and Service vectors, vary by region (j) and year (t). Sources: *Government Finances* (GF) series (Census a, various years); *Significant Features of Fiscal Federalism* (ACIR, various years); American Housing Survey (AHS), 1974-1991; *Digest of Educational Statistics* (DES), (Department of Education, various years); *Uniform Crime Reports* (UCR), (FBI, various years).

1. Mean city effective property tax rate: Continuous, Source: AHS
2. City income tax rate: Continuous, ACIR
3. City sales tax rate: Continuous, ACIR
4. Serious crimes per 100,000 population: Continuous, UCR
5. Pupil-teacher ratio in city schools: Continuous, DES
6. State income tax rate: Continuous, ACIR
7. State sales tax rate: Continuous, ACIR
8. City infrastructure stock: Continuous, GF and author's calculations (See Haughwout and Inman 1996 for details)
9. State infrastructure stock: Continuous, GF and author's calculations (See Haughwout and Inman 1996 for details)

A: Unproduced Amenities, vary by region (j). Source: US Bureau of the Census, *City and County Data Book*, 1987 and author's calculations.

1. Coastal status: Dichotomous, 0-1, author's calculations
2. Mean annual rainfall: Continuous
3. Mean annual heating degree days: Continuous
4. Mean cooling degree days: Continuous

TABLE 2: Descriptive Statistics for Second Stage Variables

Variable	*Mean*	*Std. dev.*	*Min*	*Max*
α_2 (Land price effect)	10.39	0.37	9.43	11.79
β_2 (Labor price effect)	7.25	0.20	6.12	7.98
Violent crime (per 100,000 pop)	1,268.95	596.31	385.15	4,041.08
Pupil-teacher ratio	20.12	2.63	12.60	27.40
Property tax rate (%)	1.33	0.66	0.21	3.51
State income tax rate (%)	5.33	3.94	0.00	16.00
State sales tax rate (%)	4.30	1.17	0.00	6.50
Local sales tax rate (%)	1.15	1.09	0.00	5.00
Coastal dummy	0.27	0.44	0.00	1.00
Mean rainfall (inches per yr)	34.37	11.74	7.66	61.88
Heating degree days	4,400.25	2,040.39	137.00	7,981.00
Cooling degree days	1,294.69	947.09	65.00	4,162.00
State infrastructure stock (billions of $1990)	40.68	23.17	8.19	89.36
City infrastructure stock (billions of $1990)	6.29	4.64	1.77	23.42
City infrastructure stock per capita (thousands of $1990)	8.67	3.45	1.86	19.80
City infrastructure stock, natural log of $1990 billion	1.65	0.58	0.57	3.15
City Land area (sq mi)	192.3	153.8	40.6	666.2
City population	813,936	683,041	331,163	3,487,390

TABLE 3: Estimated City Land Price and Wage Effects

	City	*Years of data**	*Mean* $\hat{\alpha}_2$	*Mean* β_2
1	Atlanta		10.39	7.08
2	Baltimore		10.36	7.27
3	Boston	74-79, 83-91	10.71	7.24
4	Buffalo	74-83	9.90	7.06
5	Chicago		10.47	7.29
6	Cincinnati		10.25	7.27
7	Cleveland		10.08	7.26
8	Columbus		10.22	7.31
9	Dallas		10.38	7.33
10	Denver		10.61	7.17
11	Detroit		9.91	7.36
12	Ft. Worth		10.16	7.27
13	Houston		10.36	7.27
14	Indianapolis		10.15	7.26
15	Kansas City, Missouri		10.11	7.21
16	Los Angeles		11.09	7.36
17	Memphis	85-91	10.16	7.23
18	Milwaukee		10.33	7.27
19	Minneapolis		10.53	7.22
20	New Orleans		10.51	7.34
21	Oakland	85-91	11.22	7.44
22	Oklahoma City		10.24	7.25
23	Omaha	85-91	10.03	7.07
24	Philadelphia		10.25	7.21
25	Phoenix		10.40	7.20
26	Pittsburgh		10.13	7.05
27	Portland, Oregon	74-83	10.44	7.21
28	San Antonio	85-91	10.17	6.88
29	San Diego		10.91	7.28
30	San Francisco		11.25	7.39
31	Seattle		10.66	7.31
32	St. Louis		10.13	7.36
33	Toledo		10.27	7.30

* 1974-1979, 1981, 1983, 1985, 1987, 1989, 1991 unless otherwise noted.

TABLE 4: Infrastructure Returns and Productivity

Estimated city effects of a one standard deviation (4.64 billion $1990) increase in mean city's infrastructure stock

Description	Estimator	Land price per acre	Land price elasticity	Present value wages per worker	Wage elasticity	**Aggregate WTP (thousands of $1990)** Firms	Households	Total	CRTS output elasticity
1/ Level	3SLS	$17,893 (2,263)	0.030 (.0038)	-$142 (361)	-0.001 (0.003)	$657,817 (128,510)	$1,870,887 (128,499)	$2,528,704 (181,733)	0.026 (0.005)
2/ Log	3SLS	25,265 (2,971)	0.042 (0.005)	1,064 (919)	0.0097 (0.0084)	1,379,335 (327,493)	2,191,271 (327,486)	3,570,606 (463,140)	0.054 (0.013)
3/ Level (reduced form land price only)	FGLS Hausman's m = 12.20, Prob=0.27	14,032 (6,123)	0.024 (0.010)	---	---	---	---	1,983,145 (1,064,000)	---
4/ Log (reduced form land price only)	FGLS Hausman's m = 13.01, Prob=0.22	5,445 (7,629)	0.009 (0.013)	---	---	---	---	769,483 (898,434)	---

Note: standard errors in parentheses

*Assumes constant returns to scale over private inputs