State infrastructure, the distribution of jobs, and productivity

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ABSTRACT

Several recent infrastructure studies have indicated that a primary effect of new investments is to redistribute economic activity within states, with little direct effect on the aggregate level of output per worker. Yet a long history of research in urban and regional economics suggests that the spatial organization of activity itself substantially affects productivity. This paper examines the *indirect* relationship between state infrastructure policies and aggregate productivity by developing and estimating a general equilibrium model of regional growth that incorporates the locational effects of public capital investments and, by extension, other fiscal differentials. The theoretical model concludes that infrastructure investments either funded or provided by higher levels of government can have significant effects on local land values and employment. Empirical results indicate that state public works have contributed to a decentralization of employment that may undermine agglomeration economies and productivity growth.

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Introduction

Empirical estimates of the effect of infrastructure on economic growth have a long and varied history. While early work suggested that the economic returns to public investment were extremely high, later research has provided a more mixed picture, while an apparent consensus has emerged that public works play a part in altering the nation's economic geography. Meanwhile, apparently unrelated research into the effect of economic geography on productivity has concluded that some geographies are more conducive to economic growth than others. In this paper, I attempt to unify these two strands of research by developing a model that incorporates infrastructure's potential to influence both the geography and the level of activity in a particular region.

The paper is organized as follows. Section II provides a review of the ever-expanding literature on infrastructure productivity, and discusses some relevant results from recent papers on economic growth. Section III presents a simple model of a regional economy with both public goods and agglomeration externalities, and develops empirical implications of the effect of infrastructure development on productivity growth. Section IV provides empirical estimates from a panel data set of US states, and the final section concludes the paper.

I. Recent research on infrastructure and agglomeration economies

Infrastructure and productivity

While public capital had appeared prominently in published empirical research on economic growth as early as Mera's (1973) study of Japanese prefectural productivity, it was Aschauer's (1989) analysis of US time series data that spurred the large amount of infrastructure work in the last decade. Aschauer's estimate that public investments had a marginal product approximately twice as high as those made by the private sector led him to the conclusion that the nation's declining productivity growth in the 1970s was attributable to the decline in public investment rates following the completion of the interstate highway system. Aschauer's study quickly became very controversial, as subsequent analyses critiqued the reliability of the time series econometrics that were the centerpiece of the paper (Aaron 1990, Hulten & Schwab, 1991).

Short national time series and the difficulty of identifying the appropriate lag structure for connecting infrastructure investment to its long run productivity led economists to explore this relationship at the state and regional level. A series of studies that applied the aggregate productivity approach to state data followed, with increasing attention paid to the estimating equation's residual term. While some of this research focused explicitly in infrastructure, other papers included public capital as one of many potential influences on state productivity (e.g., Carlino & Voith, 1992). In addition to allowing more careful specifications of the estimating equation and its residual term, regional analysis also implicitly imposes a geographic structure to the model, suggesting that public works' productivity benefits are available over only a limited geographic area. In these studies, then, aggregate output produced in state *i* is hypothesized to be affected only by infrastructure located in that state.

Working within the confines of this state-level aggregative approach, analysts have applied increasingly sophisticated statistical methods in an effort to isolate the effect of public capital on productivity. Munnell (1990) estimated aggregate production functions (APFs) over a panel of US states, and 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 that reductions in public investment were reducing productivity growth. 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 & 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.

Other authors utilized the dual cost minimization approach to the study of public capital productivity. Berndt & Hansson (1992) report that public capital is a significant cost-reducing factor in a study of the Swedish economy, while Nadiri & Mamuneas (1994) find the same for twelve U.S. manufacturing industries at the national level. Finally, Morrison & 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. Nonetheless, the estimated effects are not large enough to indicate that public capital is severely under provided in the US.

Each of these influential studies has maintained the hypothesis that state (and local) infrastructure investments' effects are on the aggregate productivity of states. That is, they implicitly assume that if infrastructure is "productive", then relative growth in state *i*'s public capital stock will cause measured worker productivity in state *i* to grow relatively faster. But even if infrastructure is a productive input, it is possible for costless increases in infrastructure to yield no increase, or even a reduction, in aggregate state output per worker. The next section outlines a simple model of an economy in which investments in productive public works reduce productivity. The key feature of this economy is spatial externalities of the sort that play a prominent role in recent analyses of urban and regional economies.

State and local governments play a dominant role in the finance and provision of public capital in the United States, and part of the reason for their dominance is the assumption that most public works serve limited geographic areas. There can be little reason to expect residents of San Diego to care about the completion of an exit ramp on the Massachusetts Pike. For analysts, this suggests that national time series may obscure relevant subnational variation in infrastructure provision and economic performance over time. The important state role in financing and selecting infrastructure investments may appear to suggest that analysis instead be conducted at the state level.

Yet states, as has often been pointed out, are political constructs, with little economic interpretation beyond the presumed uniformity of a set of regulations and tax rates. Public capital provision is by no means uniform within states, in part because of the involvement of local governments with varying preferences and budget constraints, and in part because state investments themselves are not uniform. This implies that a given increase in public capital provision in a state may have effects on the level of activity taking place in a state, the location of activity within the state, or both. The bulk of the infrastructure research conducted by economists has focused on the first of these, testing whether increased infrastructure investment gives a state a competitive advantage relative to other states. If the level and location of productive activities in a state were independent, then it would be appropriate to analyze these questions separately. But a growing body of evidence suggests that the spatial distribution of activities has important implications for growth.

Density and productivity

The idea that the spatial organization of economic activities is a significant factor in productivity and growth has a long history in urban and regional economics, and is central to recent theories for the existence of cities. Much of this work, although not all, is based on an external economies of scale argument. Geographic concentrations of production facilities and employment provide several advantages that allow individual workers and firms to be more productive.

First, geographically concentrated producers are postulated to benefit from shared inputs. If, for example, an employee unexpectedly quits, a firm can find a replacement with greater ease if it is located near other firms in a dense labor market. This will reduce inefficient “down time” and allow maximally efficient use of the firm’s private capital plant. Likewise, geographically clustered firms can share the cost and use of inputs such as those provided by producer service firms, which can operate at efficient scale when there are many potential consumers. Large concentrations of producers and consumers further allow for the sustainable production of a wider *variety* of goods and services than is available in smaller markets. A wider variety of available inputs allows producers to target their input purchases more precisely, promoting efficiency. A final major source of agglomeration benefits to producers is information spillovers. The idea that general and specialized information about products, processes and markets circulates most freely in environments conducive to frequent formal and informal contact is not new (Marshall

1890, Jacobs 1969), but it has become increasingly important in recent discussions of the sources of economic growth (Lucas 1988, Ciccone & Hall 1996, Glaeser 1998).

Empirical evidence has generally supported the idea that spatial agglomeration of activities provides a boost to productivity. Carlino & Voith (1992) find that the share of a state's population living in metropolitan areas (which is likely to be highly correlated with concentrations of jobs) is positively associated with state income growth. Glaeser et al. (1992) find that metropolitan areas that hosted a large diversity of industries grew faster between 1950 and 1990. Henderson, Black & Turner (1995) confirm and extend this finding. Perhaps the recent paper most relevant to the current study is Ciccone & Hall (1996) who study the relationship between state productivity and the distribution of jobs over counties. The authors conclude that a doubling of their county density index would lead to a six percent increase in state productivity. Quigley (1998) summarizes this empirical literature by stating that “increased size of cities and their diversity are strongly associated with increased output, productivity and growth” (pg. 136).

It is less clear at what spatial scale(s) these effects operate. For example, advantages stemming from labor market and skills pooling would presumably be equally available at all locations in a commuting shed (perhaps a PMSA). Information spillovers, on the other hand, might require face-to-face contact among high-skill individuals, suggesting a need for considerably more proximity. The evidence available to date is that agglomeration benefits appear to be operating strongly at geographic levels as small as counties. This by no means excludes the possibility that the spatial scale over which agglomeration benefits are available is even smaller; anecdotal evidence for the value of extreme proximity is found in the very high (and apparently durable) density of activities in many large city central business districts.

Infrastructure and density

We complete the background and motivation for the current work with a brief discussion of the relationship between infrastructure investment and intra-state firm location behavior. While fine-grained location has played a surprisingly small role in most studies of public capital's effect, evidence that public investments affect the spatial distribution of activity *within states* is now beginning to emerge. Two types of studies support this idea. The first demonstrate that public works increase factor prices, especially the relative price of land. Capitalization studies have found consistent evidence of a positive relationship between public investment and land (and sometimes labor) prices. Boarnet & Haughwout (2000) provide a summary of the capitalization literature for transportation infrastructure, recent specific examples include McDonald & Osuji (1995), Haughwout (1997, 1999a) and Boarnet & Chalermpong (2000). In some of this work (Haughwout 1997, 1999a), investments in one jurisdiction are found to influence factor prices in nearby jurisdictions, meaning that the benefits of infrastructure impacts are not confined to the locality making the investment. If land is assumed to be a normal good, then land price differentials reflect the relative value of locations. It follows from both theoretical and empirical research that high land values lead to intensive use and high density of activities. Fujita (1989) is the standard theoretical reference; Anas, Arnott and Small (1998) provides a thorough review of empirical results. Thus evidence that infrastructure investments are capitalized into land values is interpretable as meaning that they affect locations of either households or firms.

The most direct method of empirically analyzing the relationship between firm location and infrastructure availability is to compare some measure of private production to infrastructure. Unfortunately, good measures of firm output and investment are not generally available at the sub-state level, which helps to explain the large amount of attention that has been devoted to state-level production function analysis. Employment data, however, are available annually at the county level, and Haughwout (1999b) makes use of these in arguing that state highway investments affect the intra-state distribution of jobs. Boarnet (1998) uses a unique county-level value added data set for California to conclude that infrastructure investments attract productive activities.

Summary

We draw three related conclusions from the literatures reviewed above.

- Infrastructure's effect on aggregate state productivity is small,
- Infrastructure does influence the spatial organization of activity across the counties of a given state,
- The distribution of jobs within states has important implications for state level productivity.

The remainder of this paper attempts to explain the first of these facts as a result of the other two. In particular, we develop a theoretical model and provide empirical results suggesting that infrastructure investment tends to decentralize employment and thus indirectly reduces productivity.

II. An equilibrium model of infrastructure and agglomeration

The economy is assumed to have the property that the aggregate output obtainable from a given set of inputs depends on both public goods provision and the arrangement of activities in space, which is itself a function of the spatial distribution of public goods. Thus we have $X_T^* = \mathrm{X}(G, A(G); \mathtt{C})$, where G is public goods and $A(G)$ is a function of the spatial arrangement of public goods across jurisdictions within the region. For simplicity, think of A as a measure of employment density. Previous research has evaluated $\mathtt{M}X_T^* /\mathtt{M}G$. We are interested in the *full* effect of public works spending $\mathrm{d}X_T^* /\mathrm{d}G = \mathtt{M}X_T^* /\mathtt{M}G + (\mathtt{M}X_T^* /\mathtt{M}A)\ \mathtt{C}\ \mathrm{d}A/\mathrm{d}G$. If output is a positive function of density ($\mathtt{M}\mathrm{X}_\mathrm{T}^* /\mathtt{M}\mathrm{A} > 0$) and infrastructure investments reduce density ($\mathrm{dA/dG} < 0$) it is possible for infrastructure's total contribution to output to be negative.

Previous research has often started from the aggregate production function, and has minimized the importance of the relationship *between* infrastructure and density. Below we present a model of infrastructure's effects on individual jurisdictions and regional output.

We consider an economy made up of many freely mobile firms and households, each of which chooses from a large number of potential locations which offer both produced and naturally occurring amenities. We extend the open city fiscal model analyzed in Haughwout & Inman (2000) by including an examination of the interplay between spatial productivity externalities and public sector behavior, particularly the fiscal decisions of higher (non-local) levels of government. We abstract from naturally-occurring productive amenities in the theory, but control for them in the empirical work below. In addition, we simplify the treatment of local taxes and spending in order to focus on the issue at hand. See Haughwout & Inman (2000) for a more complete fiscal model.

Firms

Firms within the jurisdiction buy capital (K), land (L_f), and labor (N) to produce a common consumption good (X) to be sold at constant world price $\mathrm{P_X}$ (=1); X may be consumed within the jurisdiction by residents or exported and the balance of trade is endogenous. All endogenous variables of the model are denoted in *italics*; we suppress, for the time being, jurisdictional subscripts. The production technology for firms is assumed to be constant returns to scale (linear homogeneous) over these three private market inputs. Firm output is also increasing in the density (A^*) of activity taking place in their jurisdiction at equilibrium, measured by the equilibrium number of jobs in the jurisdiction (N^*), divided by the jurisdiction's fixed land area ($\mathrm{L_0}$). Finally, firms use the endogenously provided all-purpose public good (G) as an input to production. Both A^* and G are assumed to influence firm production as beneficial Hicks-neutral shifts in the marginal productivities of the private inputs.

Firms buy capital at its exogenous market price (= 1) and pay an annual cost of capital equal to the competitive rate of return (r) plus any local property tax (τ_p) levied on the value of that capital stock ($= 1 \bullet K$). Firms use land within the jurisdiction and pay the annual rental rate (R) plus the property tax (τ_p) on the value of that land ($= (R/\mathrm{r})\, L_f$). Firms hire labor (N) at the endogenously determined resident wage (W).

For production efficiency, firms within the jurisdiction maximize output defined by their common constant returns production technology needed to produce one unit of X, taking G and A^* as given -- $1 = \mathrm{X}(k, n, m, l_f; A^*, G)$, where $k = K/X$, $n = N/X$, $m = M/X$, $l_f = L_f/X$ -- subject to the exogenous local property tax rate τ_p, the endogenously determined levels of employment density (A^*) and the pure public good (G), and a constant average cost constraint inclusive of local tax payments: $\mathrm{c} = [\mathrm{r} + \tau_p]\, k + W\, n + [\mathrm{r}+\tau_p]\, (R/\mathrm{r})\, l_f$. The resulting firm demands for factor inputs, specified here as demands per unit output, are:

(1) $k = \mathrm{k}(R, W; \tau_p, A^*, G; \mathrm{r})$;

(2) $n = \mathrm{n}(R, W; \tau_p, A^*, G; \mathrm{r})$; and

(3) $l_f = \mathrm{l_f}(R, W; \tau_p, A^*, G; \mathrm{r})$.

In long-run equilibrium, firm profits may not depend on their locations. Within the jurisdiction, firms' long-run average costs must therefore equal the competitive price of the produced good (= 1). Based upon the factor demand curves above, the firms' zero excess profit constraint requires that equilibrium firm unit costs (c) equal average revenue ($1):

(4) $\Pi_0(R, W; \tau_p, A^*, G; \mathrm{r}, 1) = 1 - \mathrm{c}(R, W; \tau_p, A^*, G; \mathrm{r}) = 0$.

Households

Workers living in the jurisdiction consume three private goods -- an all-purpose consumption good (x_r), housing structures (h_r), and residential land (l_r) -- and the all-purpose pure public good (G). Work effort by residents is exogenous; there is no labor-leisure choice in our model. The residents are assumed to purchase the three private goods (x_r, h_r, l_r). Consumption goods (x_r) are purchased at the exogenous world price (=1), housing structures are constructed at the competitive price (=1) and paid for through an annual rental cost sufficient to return a competitive rate of return (r). Households purchase land within the jurisdiction at an endogenously determined annual rental price (R) and pay the local property tax (τ_{p}) levied on the value of land $(=R/\mathrm{r})\mathrm{C}l_r$) and structures (= $1\mathrm{C}h_r$). Total household expenditures on goods, housing, and land inclusive of tax payments may not exceed annual resident wage (W) earned by working at local jobs: $x_r + [\mathrm{r}+ \tau_{\mathrm{p}}]\ h_r + [\mathrm{r}+\tau_{\mathrm{p}}]\ (R/\mathrm{r})\mathrm{C}\ l_r = W$. Residents maximize a common, well-behaved utility function $\mathrm{U}(x_r, h_r, l_r; G)$ subject to this budget constraint, taking as exogenous the local property tax rate τ_{p} and the level of the local public good (G). To maintain our focus on productive externalities we assume that households are indifferent to the size of the jurisdiction in which they reside. Demand curves for x_r, h_r, and l_r are then:

(5) $x_r = \mathrm{x_r}(R, W; \tau_{\mathrm{p}}, G; \mathrm{r}, 1)$;

(6) $h_r = \mathrm{h_r}(R, W; \tau_{\mathrm{p}}, G; \mathrm{r}, 1)$; and,

(7) $l_r = \mathrm{l_r}(R, W; \tau_{\mathrm{p}}, G; \mathrm{r}, 1)$.

The long-run equilibrium requires that residents or households planning to live within the jurisdiction achieve the same level of utility as available to them elsewhere. Given the household's demands for x_r, h_r, and l_r, the indirect utility function for a typical resident can be specified and set equal to the exogenous utility ($\mathrm{V_0}$) available outside the jurisdiction:

(8) $\mathrm{V}(R, W; \tau_{\mathrm{p}}, G; \mathrm{r}, 1) = \mathrm{V_0}$.

Combining the household and firm equilibrium conditions (8) and (4) implicitly yields expressions for equilibrium land (R^*) and labor prices (W^*). Figure 1 depicts one of a set of (rising) household indifference curves and (declining) firm iso-profit curves. Equilibrium is attained when both firms and households achieve equilibrium. Note that, ceteris paribus, an increase in the size of the employment complex (N^*) will leave households unaffected, but will shift the firm iso-profit curve upward, leading to higher equilibrium wages and land prices (see Figure 2).

Local Government

The jurisdiction's government collects tax revenues and aid from higher levels of government and costlessly transforms them into public goods. In addition, higher levels of government (e.g., states) may directly provide public goods in the jurisdiction; these are financed from the state tax base. We ignore the possibility of debt finance, which will not alter the conclusions here as long as information on debts is freely available and property markets are forward looking. The level of local public good available in a given jurisdiction is then

(9) $G = \tau_p \cdot (R^* \cdot L_0 + N^* h_r + X^* k) + A + D + (1 - \delta) G_{t-1}$

where L_0 is the (fixed) land area of the jurisdiction, A is aid from, and D is direct public goods provision by, higher levels of government. G_{t-1} is last year's infrastructure stock, which depreciates at annual rate δ. Note that (9) is an implicit function, since land prices (R^*) and the optimizing levels of housing (h_r) and productive (k) capital all depend on G.

Aggregate jurisdictional output and employment

Individual firms make their hiring decisions in a location based on its endogenous local price vector $\{R^*, W^*\}$, agglomeration (A^*), and public goods (G). The model results in 10 equations for the 10 endogenous aggregate variables: equilibrium land and labor prices, R^* and W^*; city residents' consumption of the composite good, X_c^*, housing capital H^*, and land, L_r^*; firm hiring of workers N^*, private capital K^*, and land L_f^*, aggregate output produced X^*, and equilibrium public good provision G.[1] Here we focus on aggregate output and employment.

Since production and worker housing require land, the binding constraint (finite resource) that determines the jurisdiction's aggregate output is its land area. Assuming that the local land market clears implies that, at equilibrium prices,

$$\mathrm{L}_0 = L_f^* + L_r^* = X^* \,\mathtt{C}\, [\mathrm{l}_\mathrm{f}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r}) + \mathrm{n}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r}) \,\mathtt{C}\, \mathrm{l}_\mathrm{r}(R^*, W^*; \tau_\mathrm{p}, G; \mathrm{r}, 1)]$$

or

$$(10)\ X^* = \mathrm{L}_0 / L_1^*$$

where $L_1 = \mathrm{l}_\mathrm{f}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r}) + \mathrm{n}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r}) \,\mathtt{C}\, \mathrm{l}_\mathrm{r}(R^*, W^*; \tau_\mathrm{p}, G; \mathrm{r}, 1)$ is the land required to produce each unit of output. Equation (10) makes plain the close relationship between output and the intensity of land use: as L_1 falls, land is used more intensively and output produced in a given geographic area increases.

Equilibrium employment is then

$$(11)\ N^* = \mathrm{n}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r}) \,\mathtt{C}\, X^*$$

which is an implicit function of N^*. Output per worker is

$$(12)\ \mathrm{p} = \mathrm{X}^*/\mathrm{N}^* = 1/\ \mathrm{n}(R^*, W^*; \tau_\mathrm{p}, A^*, G; \mathrm{r})$$

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[1] See the Haughwout & Inman (2000) for the full list of equations.

Equilibrium effects of exogenous improvements in public goods

We consider the effects on this equilibrium of exogenously-funded changes in the level of public goods provided. In particular, we are interested in the equilibrium relationship between aggregate production, worker productivity and public goods provided by non-local levels of government.

Infrastructure will increase measured output per worker when $dn/dG < 0$. A cautionary note is that equilibrium productivity per worker will usually fall when infrastructure is sufficiently attractive to households that $MW^*/MG < 0$. This cannot, however, be interpreted to mean that infrastructure is unproductive, since aggregate output will rise, just not as fast as aggregate employment rises.

The critical question we analyze next is how infrastructure conditions in one jurisdiction influence conditions in other places. Productive new public investments in a given jurisdiction shift the firm profit curve upward, to

Consider a region whose land area is equally divided into two jurisdictions, *i* and *j*, each with fixed land areas. A productive new infrastructure in jurisdiction *i* reduces, ceteris paribus, the cost of producing *X* there. Jurisdiction *j*'s wages and land prices must fall for it to remain competitive; see figure 2. The reduction in *j*'s equilibrium prices induces increases in employment and land use per unit of output. Put another way, jurisdiction *j* becomes less dense and its worker productivity falls. Of course, these same variables all concurrently rise in jurisdiction *i*, and the effect on overall productivity is unclear. We note, however, that if the reduction in agglomeration economies in *j* is larger than the gain in productivity in *i*, then aggregate output and productivity will fall in the region as a whole.

The expression for aggregate output change induced by an increase in public investment in region 1 is then $dX_T^*/dG_1 = \Sigma_j dX_j^*/dG_1 = \Sigma_j\ (-X_j^*/L_{1j})\ (dL_{1j} / dG_1)$. In jurisdiction 1, $dL_{11} / dG_1 < 0$, but in all other jurisdictions $dL_{1j} / dG_1 > 0$. If overall density in the region is reduced as a result of the investment in jurisdiction 1, then aggregate regional output may fall, in spite of the fact that the investment is "productive" in the traditional sense that it reduces unit production costs for every firm that utilizes it. We next turn to empirical evidence on the equilibrium effects of infrastructure investments conducted by state governments.

III. Data and estimation

A comprehensive understanding of the role of infrastructure in productivity growth requires an empirical design which captures both its direct and indirect (locational) effects. We thus estimate a two-stage model. In the first step, the intrastate distribution of jobs is modeled as a function of infrastructure and intra-state variation in exogenous productive traits.

(13) $A_s^* = A(D_s; Z_s)$

where A is a measure of county employment density, D measures state-owned infrastructure, and Z is a vector of intra-state variation in exogenous and pre-determined traits. We assume that local infrastructure is provided so as to maximize local benefits, and that state infrastructure decisions are the crucial determinants of intra-state variation in infrastructure conditions.

In the second equation, state-level economic growth in state *s* is determined by aggregate infrastructure, employment density, and a set of exogenously determined state traits such as state land area, climate and location.

(14) $X_{T,s}* = X(D_s, A_s*; Q_s)$

where X is aggregate state output and Q is the set of exogenous state traits.

Employment and output data for the analysis are from the *Regional Economic Information System* (REIS) data set (US Census Bureau, 1998). County and state land area data are from *County and City Data Book* (Census 1975). The highway infrastructure stocks were constructed by applying the perpetual inventory technique to capital outlay data reported in the 1915-1992 issues of *State Government Finances* (US Census Bureau, various). The data are reported for the 48 contiguous states. Alaska, Hawaii and the District of Columbia are excluded.

Table 1 reports descriptive statistics for the key variables in the analysis. For the current analysis, employment density is measured by the county-level Herfindahl index. For state s in year t, this index is calculated as $H_{s,t} = \sum_{c \in s} \phi^2_{c,t}$, where $\phi_{c,t}$ is county c's share of total state employment in year t. The Herfindahl is an appropriate index of density in that it incorporates information from all of a state counties. It has the drawback of depending on county size. For example, Delaware has four counties, while Texas has 255. Even if jobs were perfectly evenly divided over counties in both states, their Herfindahl indexes would differ. In this extreme example, $H_{DE} = 0.25$, while $H_{TX} = 0.004$. Thus in this example, as well as in general, the Herfindahl index is negatively related to the number of counties in the state. This dependence of the Herfindahl on the artificial definitions of counties, however, turns out to be an advantage, as we discuss below.

Table 2 provides more detail on the national density declines. Note that there is very significant interstate variation in the rate of employment decentralization. The fastest decentralization (in percentage terms) was in Rhode Island, while Nevada boasted the highest rate of centralization. (Note the connection with the highway density figures in Table 1.) By coincidence, half the states registered increases, and half declined. The unweighted mean of the state changes was +0.08%, but when weighted by employment, the mean change was -0.44%. The reason for this difference is easy to see in from Table 2. Contrast, for example, the top three centralizing states (Nevada, Arizona and New Mexico - all in the arid southwest) with the top three decentralizing states (Rhode Island, Illinois and Michigan - all in the rust belt). Most of the larger states (measured by 1977 employment) witnessed declines in their Herfindahl indexes over this period, with Texas the important exception. That is, the states that saw declines in their inter-county employment concentration levels were larger than those that saw increases.

While the largest percentage increases since the early 1970s have been in non-transportation infrastructure, transportation infrastructure remains the dominant form of physical wealth owned by state governments (Haughwout 1999b). Given highways' intended effects on transportation cost, they are likely to generate the largest changes in employment decentralization and are thus the focus of our analysis. Real-valued infrastructure stocks have grown in virtually all states, even in those with relatively low or negative employment increases. The exceptions are Pennsylvania, California and Vermont, where the replacement value of highways declined slightly. More than twothirds of the states (33) registered double digit increases, with Georgia's growth a brisk 48% (1.5% per year).

Figures 3 and 4 demonstrate that in the nation as a whole, employment decentralization as measured by declines in the (weighted) Herfindahl went hand-in-hand with infrastructure growth, especially after 1985, when road building picked up. (This increase was a result of the 1982 federal Transportation Assistance Act, a measure designed to counteract the effects of the 1982 recession).

Estimation

We estimate the variants of the two equation system

(13') $H_{s,t} = \alpha + \beta_1 * \text{Highways}_{s,t} + \beta_2 * \#\text{Counties}_s + \varepsilon_{s,t}$

(14') $X_{s,t}* = \gamma + \lambda_1 * \text{Highways}_{s,t} + \lambda_2 * H_{s,t} + \mathbf{l_3 * Z_{s,t}} + \mu_{s,t}$

A* (measured here by the state-level Herfindahl, $H_{s,t}$) is modeled as a function of state highways and the number of counties in each state. Aggregate output produced in each state (measured as Gross State Product, GSP) is a function of Highways, the distribution of jobs over space, H, and exogenous productive characteristics of state s.

Estimation of (13) and (14) is by either OLS or instrumental variables. Note that the Herfindahl index that we use to measure density is only a proxy for the underlying spatial process that relates employment density to output and productivity growth. $\#\text{Counties}_s$ is excluded from the output regression (14'), reflecting our identifying assumption that the division of the state into counties ought not to influence the real economy. We include the number of counties (or average county size) in (13') as it is expected (negatively) to affect our density proxy. Note that the full effect of infrastructure on output is given as

(15) $dX_{s,t}^*/dD_s = \lambda_1 + \beta_1 * \lambda_2$

We anticipate that $\lambda_1, \lambda_2 > 0$, but that $\beta_1 < 0$. If infrastructure's effect on density is negative enough, then $dX_{s,t}^*/dD_s$ may be negative.

Table 4 reports estimates between the county employment Herfindahl index and state highway infrastructure. In columns (1) and (2) the dependent variable is measured as the (log) level of the index. The two specifications differ in their treatment of state land area, which is excluded from the column (1) results. As expected, the number of counties is significantly negatively related to the Herfindahl index, regardless of the inclusion of state land area. More importantly, the coefficient on state highway stocks is a precisely estimated -0.026 in each column. This suggests that a ten percent increase in the replacement value of state highway stocks reduces state-level employment density by 2.6%.

The results in columns (3) and (4) are based on growth in the log Herfindahl index. Here, the number of counties has switched sign and is significantly positive. Note that since number of counties varies only across but not within states, this variable is a weak instrument for identifying shifts in a given state's Herfindahl index over time. This weakness of the identification strategy adopted here is discussed further below. Note that highway stocks, which do vary within states over time, are again estimated to be negatively related to density, and the estimates are precise. In columns (3) and (4), however, the elasticity has fallen to -0.0008, indicating that a ten percent increase in the replacement value of state highway stocks reduces state-level employment density by just 0.008%.

Table 5 reports the results of state-level GSP level and growth equations. Columns (1) and (2) report OLS estimates with and without the Herfindahl index. Note that the inclusion of the Herfindahl "cleans up" the effect of state highway infrastructure, which is estimated to have a significantly negative effect on output in column (1) and a positive (although imprecisely estimated) effect in column (2). More importantly, the elasticity of state GSP with respect to our density measure is a precisely estimated 0.496 in column (2). A ten percent increase in a state's employment density (about one standard deviation) is thus associated with a five percent increase in real GSP (about 4% of a standard deviation). Note that the direct infrastructure elasticity (.008 in column 2 of Table 5) is reduced by an indirect effect of -0.013 (= -0.026*0.496), leaving a total effect of -0.005.

Column (5) in Table 5 reports a similar specification, but in first differences. Again, highways' output effect increases substantially with the inclusion of the employment herfindahl (compare columns 4 and 5), and growth in the Herfindahl index is positively and significantly related to GSP growth. Here, combining the direct (0.147) and indirect (-.0008*2.784) highway elasticities yields a net elasticity point estimate of +0.144, barely distinguishable from the direct effect alone.

Columns (3) and (6) in Table 5 report the results of instrumental variables estimation of the level and growth in (log) GSP. In both cases, the number of counties in each state serves as the identifying instrument. As noted above, this measure is, by construction, negatively related to the level of the Herfindahl index, but does not vary over time within a state. Thus temporal variation in the Herfindahl index within each state is not identified. In column (6) of Table 5, the instrumented version of the Herfindahl is recovered from the regression reported in column (4) of Table 4. In this regression, the coefficient on the (predicted) Herfindahl index growth is 25.49, implausibly large, in spite of its relatively small standard error. Note that the 95% confidence interval for this estimate extends to zero, thus it includes the other point estimates of the density elasticity reported in Table 5. Note also that the R-squared for this regression is more than 50% smaller than its OLS counterpart in column (5). Taking this point estimate at face value, we estimate the full effect of highways on output at 0.118 (= 0.121 - .0008*25.49).

More reliable is the level IV regression reported in column (3). Here, the substitution of the Herfindahl predicted by the regression in column (2) of Table 4 rests on cross-sectional variation in the instrument, counties. The R-squared for this regression is only slightly smaller than its OLS counterpart in column (2), and the point estimate of the density-output elasticity is a precisely estimated 1.896. Combining the estimates in column (3) of Table 5 and (2) of Table 4, we estimate the total highway elasticity at 0.175 (= 0.225 - 0.026*1.896).

IV. Conclusion

The estimates reported here suggest positive effects of highway infrastructure on aggregate real output at the state level that are significantly diminished by highways' effects on density. Employment density is also found to be positively associated with state output and its growth rate. Most important to the current policy debate, however, is the finding that highways serve to decentralize employment, thereby reducing their effect on productivity.

Future work will expand the list of explanatory variables to include inter- and intra-state variation in other exogenous determinants of state output and productivity. Factors that appear likely to be important are state and local fiscal policies other than highway capital provision (especially taxes), the state regulatory environment and state environmental amenities. Of particular importance is the need for an instrument for county employment density that varies over time within states, but is unrelated to state output. For the time being, we are encouraged that the relationship between density and infrastructure is a potentially important, and often overlooked, factor in state growth.

References

Aaron, H. 1990. "Discussion of `Why is Infrastructure Important?'" in A. Munnell, ed. *Is There a Shortfall in Public Capital Investment?*.

Anas, A., R. Arnott and K. Small. 1998. AUrban Spatial Structure,@ *Journal of Economic Literature*, Vol. 36, No. 3, pp. 1426-1464.

Aschauer, D. 1989. "Is Public Expenditure Productive?" *Journal of Monetary Economics*, Vol. 23, pp. 177-200.

Berndt, E. & B. Hannsson. 1992. " Measuring the Contribution of Public Infrastructure Capital in Sweden," *Scandinavian Journal of Economics*.

Boarnet, M. 1998. “Spillovers and the Locational Effect of Public Infrastructure,” *Journal of Regional Science*, Vol. 38, no. 3, pp. 381-400.

Boarnet, M. & A. Haughwout. 2000. ADo Highways Matter? Evidence and Implications of Highways' Influence on Metropolitan Development,@ Working paper, Brookings Institution.

Boarnet, M. & S. Chalermpong. 2000. "New Highways, Urban Development, and Induced Travel," working paper, University of California, Irvine.

Carlino, G. & R. Voith. 1992. "Accounting for Differences in Aggregate State Productivity," *Regional Science and Urban Economics*, Vol. 22.

Ciccone, A. and R. Hall, 1996. “Productivity and the Density of Economic Activity,” *American Economic Review*, Vol. 86, no. 1, 54-70.

Fujita, M. 1989. *Urban Economics*, New York: Oxford.

Garcia-Mila, T., T. McGuire and R. Porter. 1996. "The Effect of Public Capital in

State-Level Production Functions Reconsidered," *Review of Economics and Statistics*, Vol. 78, pp. 177-180.

Glaeser, E. et al. 1992. “Growth in Cities,” *Journal of Political Economy,* Vol. 100, No. 6, pp. 1126-1152.

Glaeser, E. 1998. “Are Cities Dying?” *Journal of Economic Perspectives,* Vol. 12, No. 2, pp. 139-160.

Haughwout, A. 1997. ACentral city infrastructure investment and suburban house values,@ *Regional Science and Urban Economics*, 27, 199-216.

______. 1999a. ARegional Fiscal Cooperation in Metropolitan Areas: An Exploration,@ *Journal of Policy Analysis and Management*, Fall.

______. 1999b. AState Infrastructure and the Geography of Employment,@ *Growth and Change,* Fall.

______ and R. Inman. 2000. "Fiscal Policy in Open Cities with Firms and Households," forthcoming *Regional Science and Urban Economics.*

Holtz-Eakin, D. 1994. "Public-Sector Capital and the Productivity Puzzle," *Review of Economics and Statistics,* Vol. 76, pp. 12-21.

Hulten, C. and R. Schwab. 1991. "Is there too little Public Capital?" presented at conference *Infrastructure Needs and Policy Options for the 1990s,* American Enterprise Institute.

Lucas, R. 1988. “On the Mechanics of Economic Development,” *Journal of Monetary Economics*, 22, July.

McDonald, J. & C. Osuji (1995) AThe Effect of Anticipated Transportation Improvement on Residential Land Values,@ *Regional Science and Urban Economics*, 25, 3, pp. 261-78.

Mera, K. 1973. "Regional Production Functions and Social Overhead Capital: An Analysis of the Japanese Case," *Regional Science and Urban Economics*, Vol. 3, pp. 157-185.

Nadiri, M. and T. Mamuneas. 1994. “The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of US Manufacturing Industries,” *Review of Economics and Statistics*, Vol. 76, No. 1, pp. 22-37.

Partridge, M.D. and D.S. Rickman (1999), “Static and Dynamic Externalities, Industry Composition, and State Labor Productivity: A Panel Study of States,” *Southern Economic Journal,* 66:2, pp. 319-335.

Quigley, J. 1998. “Urban Diversity and Economic Growth,” *Journal of Economic Perspectives*, Vol. 12, No. 2, pp. 127-138.

Morrison, C. and A. Schwartz. 1996. "State Infrastructure and Productive Performance," *American Economic Review*, Vol. 86, no. 5, pp. 1095-1111.

Munnell, A. 1990. “How Does Infrastructure Affect Regional Economic Performance?” in A. Munnell, ed. *Is There a Shortfall in Public Capital Investment?.*

Table 1: Descriptive Statistics

	Mean	Standard deviation	Coefficient of Variation	Minimum	Maximum
Real GSP (Millions of $1992)	105,960.6	126,105.4	1.190	7,255.0 Vermont, 1977	846,065.0 California, 1990
Total employment	5,088,587	5,352,990	1.052	461,176 Wyoming, 1977	33,909,008 California, 1990
Real GSP per worker ($1992/worker)	19,481.4	2,536.4	0.130	14,918.3 S. Carolina, 1977	28,121.7 Delaware, 1992
Real highway stock (thousands of $1990)	14,509,176	11,564,534	0.797	2,407,838 Vermont, 1992	65,867,858 Texas, 1992
Highway density ($/sq. mi.)	241,076	302,356	1.254	12,170 Nevada, 1977	1,542,230 Rhode Island, 1992
Herfindahl for county employment share	0.2827	0.0279	0.099	0.2573 N. Carolina, 1977	0.3861 Delaware, 1989
Total land area (sq. mi.)	123,146	92,745	0.753	2,099 Rhode Island	524,277 Texas
Number of counties	65.1	45.2	0.694	4 Delaware	255 Texas
Average county area (sq. mi.)	2,535.0	2,822.0	1.113	349.8 Rhode Island	14,177.2 Arizona

Note: There are 768 observations, representing the 48 contiguous states over the period 1977-1992

Table 2: 1977-1992 Change in County Employment Herfindahl, by state

	% change	Rank		% change	Rank
Alabama	-0.24%	28	Nebraska	2.17%	4
Arizona	3.37%	2	Nevada	4.24%	1
Arkansas	0.53%	17	New Hampshire	0.29%	21
California	-2.16%	44	New Jersey	-0.61%	34
Colorado	-2.31%	45	New Mexico	2.26%	3
Connecticut	-0.29%	31	New York	-1.22%	41
Delaware	-0.24%	29	North Carolina	0.65%	14
Florida	-1.16%	40	North Dakota	1.84%	8
Georgia	-0.66%	36	Ohio	-0.28%	30
Idaho	2.05%	6	Oklahoma	0.57%	16
Illinois	-2.80%	47	Oregon	-0.86%	38
Indiana	0.10%	22	Pennsylvania	-0.74%	37
Iowa	0.83%	12	Rhode Island	-4.09%	48
Kansas	1.80%	9	South Carolina	0.42%	20
Kentucky	-0.47%	32	South Dakota	2.15%	5
Louisiana	-0.95%	39	Tennessee	-0.04%	26
Maine	0.85%	11	Texas	0.50%	18
Maryland	-1.85%	43	Utah	-0.03%	25
Massachusetts	0.09%	23	Vermont	1.55%	10
Michigan	-2.40%	46	Virginia	0.62%	15
Minnesota	0.43%	19	Washington	1.91%	7
Mississippi	0.04%	24	West Virginia	-0.21%	27
Missouri	-0.64%	35	Wisconsin	-1.23%	42
Montana	0.68%	13	Wyoming	-0.52%	33
Unweighted state mean	0.08%				
Employment-weighted mean	-0.44%				

Table 3: 1977-1992 Change in State Highway Infrastructure, by state

	% change	Rank
Alabama	19.2%	18
Arizona	44.5%	2
Arkansas	16.5%	22
California	-8.7%	48
Colorado	23.6%	14
Connecticut	15.6%	25
Delaware	20.2%	16
Florida	37.8%	3
Georgia	48.1%	1
Idaho	29.3%	7
Illinois	16.2%	24
Indiana	12.4%	33
Iowa	12.5%	32
Kansas	12.8%	31
Kentucky	21.2%	15
Louisiana	18.8%	19
Maine	2.1%	44
Maryland	26.7%	10
Massachusetts	6.3%	39
Michigan	1.1%	45
Minnesota	14.5%	27
Mississippi	9.4%	36
Missouri	6.3%	40
Montana	14.4%	28
Nebraska	20.2%	17
Nevada	26.9%	9
New Hampshire	4.0%	42
New Jersey	15.4%	26
New Mexico	27.0%	8
New York	7.8%	38
North Carolina	17.4%	20
North Dakota	9.9%	34
Ohio	3.1%	43
Oklahoma	16.3%	23
Oregon	13.5%	30
Pennsylvania	-4.1%	47
Rhode Island	9.6%	35
South Carolina	17.2%	21
South Dakota	4.5%	41
Tennessee	25.0%	12
Texas	36.7%	4
Utah	30.5%	6
Vermont	-2.6%	46
Virginia	23.8%	13
Washington	25.1%	11
West Virginia	14.0%	29
Wisconsin	9.2%	37
Wyoming	32.2%	5
Unweighted state mean	16.74%	

Table 4: Highways and Employment Density

Dependent variable:	Log County Emp. Herfindahl		Δ log Herfindahl	
Variable	(1)	(2)	(3)	(4)
Log state land area	---	-0.015	---	0.0005
		(.003)		(.0001)
# Counties	-0.0007	-0.0005	0.000007	0.000002
	(.0001)	(.0001)	(.000002)	(.000002)
Log state highways	-0.026	-0.026	-0.0008	-0.0008
	(.0048)	(.0047)	(.0001)	(.00009)
Equation R-squared	0.272	0.297	0.172	0.238

Note: Standard errors in parentheses
There are 720 observations: 48 states over 15 years, 1978-1992
All equations include year effects, which are jointly significant at standard confidence intervals

Table 5: Highways, Employment Density and Output

Dependent variable:	Log of Gross State Product			Δ Log GSP		
Estimation:	OLS	OLS	IV	OLS	OLS	IV
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Log state land area	-0.013	-0.006	0.012	-0.002	-0.003	-0.013
	(.004)	(.004)	(.011)	(.001)	(.001)	(.006)
Log GSP in '77	1.0446	1.0009	0.878	-0.0004	0.001	0.013
	(.012)	(.013)	(.066)	(.001)	(.001)	(.007)
Log state highways	-0.069	0.008	0.225	---	---	---
	(.017)	(.019)	(.115)			
Δ log highways	---	---	---	0.0149	0.147	0.121
				(.005)	(.094)	(.161)
Log County Emp. Herfindahl	---	0.496	1.896	---	---	
		(.059)	(.729)			
Δ log Herfindahl	---	---	---	---	2.784	25.49
					(.618)	(12.9)
Equation R-squared	0.987	0.988	0.979	0.373	0.391	0.177

Note: Standard errors in parentheses
There are 720 observations: 48 states over 15 years, 1978-1992
All equations include year effects, which are jointly significant at standard confidence intervals

Figure 1: Wage and Land Price Equilibrium

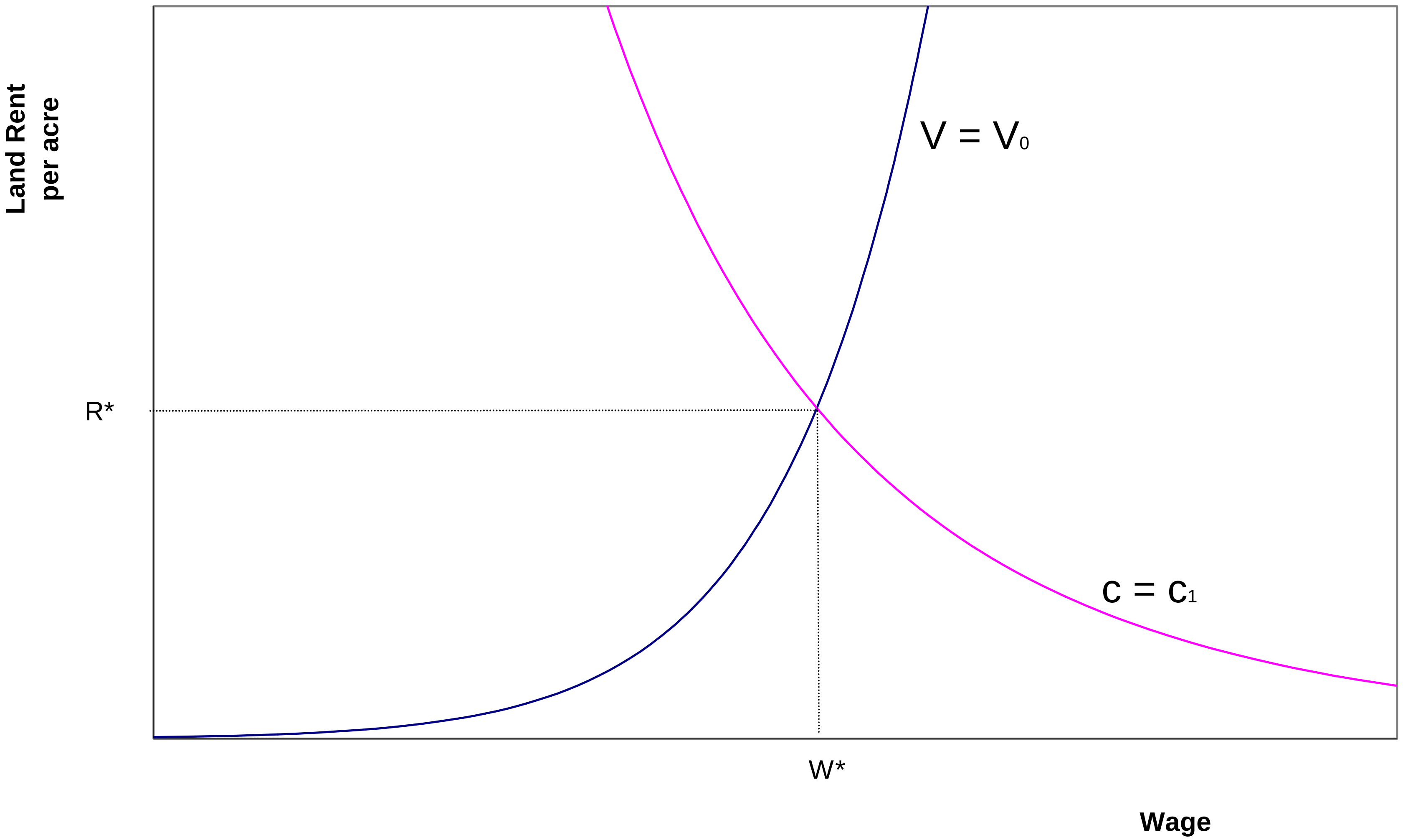

Figure 2: Wage and Land Price Equilibrium with lowered costs elsewhere

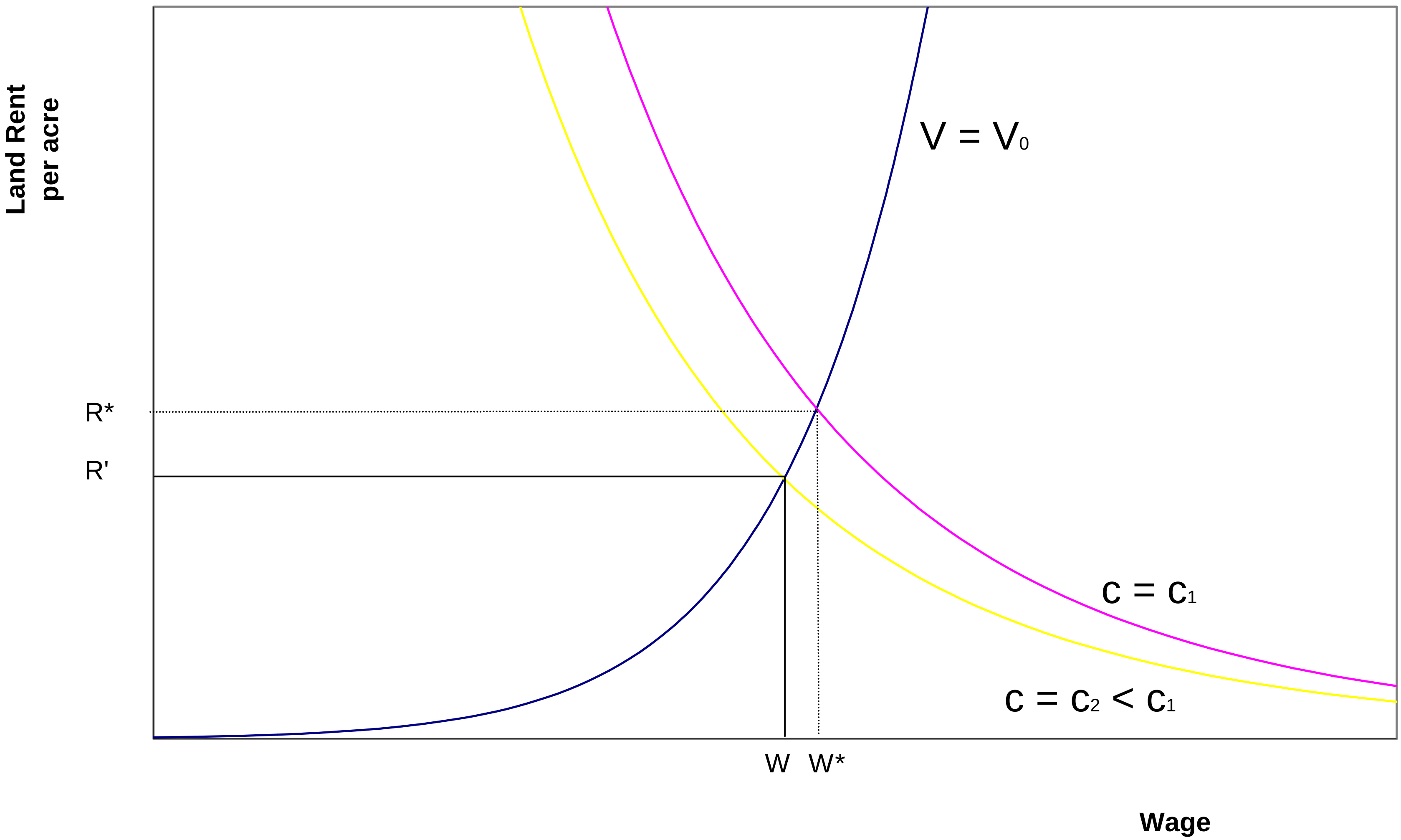

Figure 3: Infrastructure & Employment density

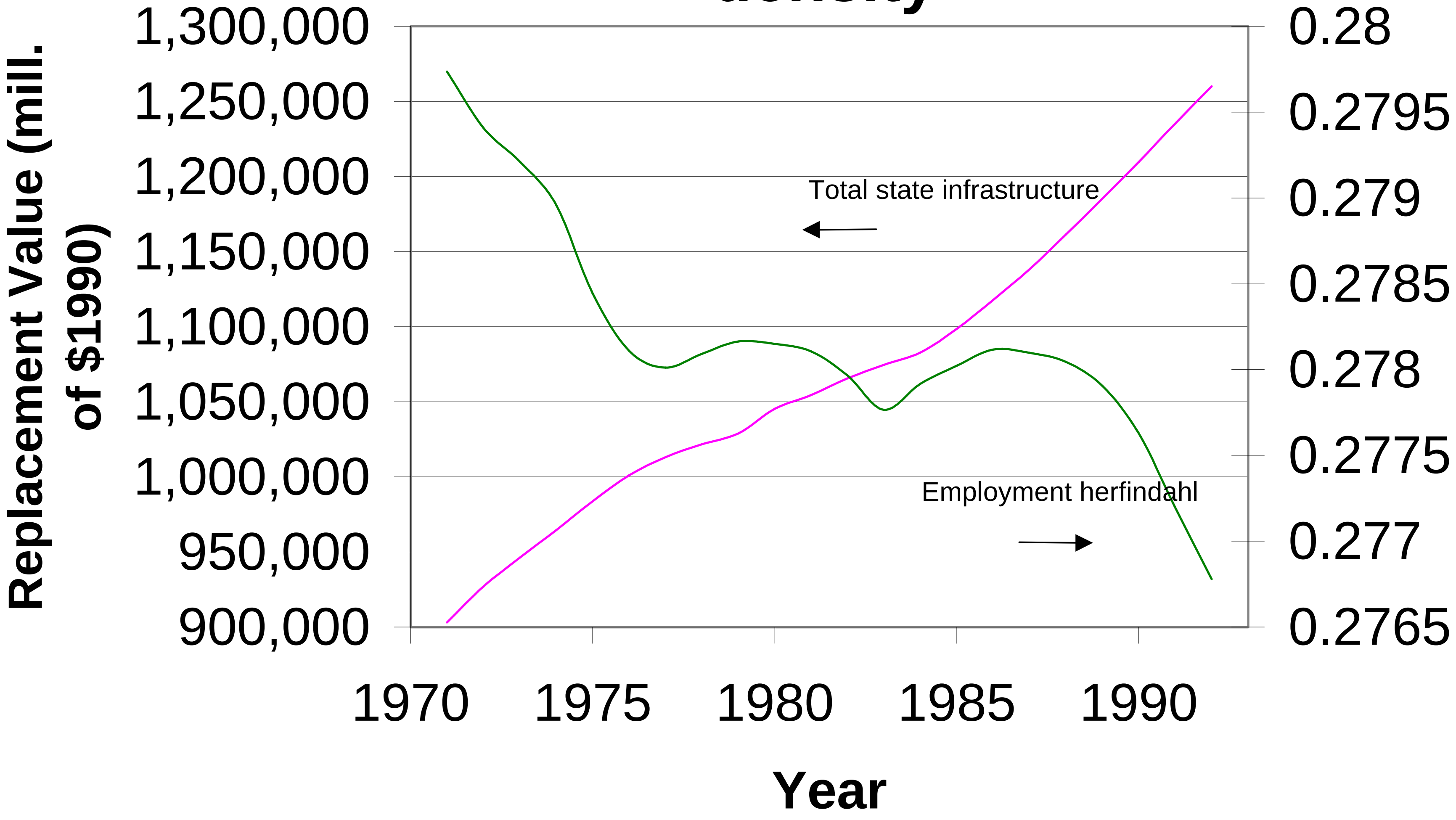

Figure 4: Roads & Employment density