DOES INFRASTRUCTURE INVESTMENT INCREASE TH PRODUCTIVITY OF MANUFACTURING INDUSTRY IN THE U.S.?

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I. Introduction

The American South started the post World War II era as the poorest region of the country. Per capita disposable income was less than 70 percent of the national level and the South produced less than 13 percent of national manufacturing output. Over the ensuing 40 years, the South grew much faster than the most of the rest of the nation. As a result, incomes in the South are now 90 percent of the national average and the South now produces 22 percent of all manufacturing output.

Our previous studies of regional manufacturing examined the sources of this differential growth and concluded that the superior growth rate of the Sun Belt region was explained entirely by the more rapid growth in capital and labor input (Hulten and Schwab 1984,1991). Differences in the regional growth rates of total factor productivity (TFP) were found to be negligible. This led to the further conclusion that regional differences in factors like infrastructure investment did not translate in to differences in the productive efficiency of manufacturing industry. This conclusion is of some interest for the debate over the adequacy of the nation's infrastructure capital, since it suggests that there were no technological spillovers among manufacturing industries associated with infrastructure investment. Thus our findings in those earlier papers lend no support for the very high rates of return to infrastructure found by Aschauer (1989,1990) and others.[1]

Equal *growth rates* of regional TFP do not, however, imply equal *levels* of TFP, and our findings are thus consistent with different hypotheses about the nature of regional growth. For example, the Sun Belt manufacturing industry may have been initially more backward than the older Snow Belt regions and the gap continued despite TFP growth in all regions. Deficient infrastructure capital is one possible reason for a low level of TFP, although the failure to adopt best-practice technologies or an industry mix at the low end of the "technology ladder" are other explanations (factors often cited when discussing the growth of developing countries)[2]. On the other hand, the equality of regional TFP growth rates is also consistent with the equality of TFP levels. In this alternative view, the Sun Belt states produced manufactured goods with exactly the same technological efficiency as elsewhere despite differences in infrastructure endowment.

We attempt to sort out these possibilities be extending our original analysis in the direction pioneered by Jorgenson and Nishimizu (1978). Prior to Jorgenson and Nishimizu, studies of the sources-of-growth of different countries or regions had to be content with Solow's residual measure of TFP growth. The contribution of Jorgenson and Nishimizu was to show how to convert the Solow (1957) residual into a measure of the level of TFP. We implement this approach using 1970-1986 data from the Census and Annual Survey of Manufactures for the nine Census divisions of the U.S. and national data from the Bureau of Labor Statistics and Bureau of Economic Analysis. We then perform a modified version of the Hall (1988) invariance test using the regional levels of TFP and check to see if there is a statistically significant correlation between these levels and the level of infrastructure capital in each region. Combining the Hall methodology with the Jorgenson-Nishimizu model allows us to avoid one of the main problems associated with the analysis of TFP: an untetsed assumption of perfect competition and constant returns to scale.

The remainder of the paper has the following organization. Section II sets out the sources of growth framework and our proposed tests of several alternative models of regional growth. In Section III we present the data we use in our study and in Section IV we set forth our econometric results. Section V includes a brief summary and conclusions.

II. Testing the Alternative Models

Our extension of the Jorgenson-Nishimizu model starts with the assumption that there is a Hicks-neutral production function for manufacturing industry within each region. We assume that manufactured goods in region i in year t,

Q_{it}, are produced using privately-owned capital K_{it}, labor L_{it}, intermediate inputs M_{it}, and public capital B_{it}:

$$(1) \qquad Q_{it} = A_{i0} B_{it}^{\gamma_i} e^{\lambda_i t} F^i(K_{it}, L_{it}, M_{it}, B_{it})$$

Our specification of the public capital variable follows Meade (1952) and Berndt and Hansson (1991) in identifying two ways that public capital influences output. First, it yields direct productive services and thus appears as an argument of $F^i(\cdot)$ (as, for example, when trucks and drivers are combined with public highways to produce transportation services). Second, public capital acts as an "environmental" factor or "systems spillover" which enhances the productivity of some or all of the private inputs. This is represented by the B_{it} component of the technical efficiency term. The infrastructure variable is assumed to enter (1) in constant elasticity form, and the parameter γ_i thus measures the strength of the within-region spillover effect.[3] The other arguments of technical efficiency include the level of regional technical efficiency in some initial year 0, A_{i0}, and the growth rate of technical change, λ_i. The product of these three terms defines the level of total factor productivity.

Regional differences in the level TFP can arise, in this framework, from variations in the quantity of infrastructure capital, different initial levels of TFP, or regional differences in the growth rate of technical change. If some regions are relatively backward for any of these reasons, this backwardness may (in and of itself) give rise to convergence in TFP levels, as in Dowrick and Nguyen (1989). This convergence may be enhanced if there is an infrastructure gap that can be closed. However, under the circumstances posited in endogenous growth theory, regional differences in TFP levels may lead to divergent growth rates among regions.

One mechanism through which infrastructure investment may promote divergent growth is analyzed in Barro (1990). The Barro framework is a variant of the Lucas-Romer-Rebelo endogenous growth model in which public infrastructure capital is fixed by policy at a constant fraction of the private capital stock, i.e., $B_{it} = \tau_i K_{it}$. The production function in this case can then be written as

$$(2) \qquad Q_{it} = [A_{i0} B_{it}^{\gamma_i}] K_{it}^{\alpha_i} L_{it}^{\beta_i} M_{it}^{\eta_i} = A_{i0} \tau_i K_{it}^{\alpha_i+\gamma_i} L_{it}^{\beta_i} M_{it}^{\eta_i}$$

If direct input elasticities ($\alpha_i+\beta_i+\eta_i$) sum to one, private producers believe that production takes place under constant returns to scale and a competitive equilibrium may be established. However, the true elasticity of output with respect to total capital ($\alpha_i+\gamma_i$) exceeds the direct elasticity, implying increasing returns to scale and the possibility of endogenous growth.

The Sources of Growth Framework

One major advantage of the Solow-Jorgenson-Nishimizu framework is that it is unnecessary to estimate all of the parameters of the production function. Instead, the measurement of TFP can be based on a two stage procedure that makes use of nonparametric index number techniques. The first step involves the computation of the Solow residual under the assumption that public capital has no effect on private output growth.[4] The continuous time version of the Solow residual has the form:

$$(3) \qquad \dot{A}_{it}^{S} = \dot{Q}_{it} - \pi_{it}^{K} \dot{K}_{it} - \pi_{it}^{L} \dot{L}_{it} - \pi_{it}^{M} \dot{M}_{it}$$

where dots over variables denote rates of growth and the π^{X}_{it} are income shares. Each term in (3), except the growth rate of the Solow residual, can in principle be measured directly, and the growth rate of the technology index can thus be estimated as a residual.

We link the regional Solow level index numbers to the technical efficiency terms in the underlying production function (1) in the second stage of the analysis. The true growth rate of efficiency is derived from (1) and equals

$$\dot{A}_{it} = \dot{Q}_{it} - \epsilon^{K}_{it}\dot{K}_{it} - \epsilon^{L}_{it}\dot{L}_{it} - \epsilon^{M}_{it}\dot{M}_{it} - \epsilon^{B}_{it}\dot{B}_{it} = \gamma_{i}\dot{B}_{it} + \lambda_{i} \tag{4}$$

where is ϵ^{X}_{it} is the elasticity of output with respect to input X.

A comparison of the Solow residual A^{S}_{it} with the true efficiency term A_{it} reveals two major differences: in the Solow residual, public capital's contribution to output has been ignored and the income shares π^{X}_{it} are assumed equal to the corresponding output elasticities ϵ^{X}_{it}. The second issue does not pose a problem for income shares of the variable private factors (labor and intermediate input) when the economy is in competitive equilibrium and they are paid the value of their marginal products. However, it is not generally true that $\epsilon^{K}_{it} = \pi^{K}_{it}$, even under competitive assumptions, and the wedge between the two can introduce a bias into the Solow residual.[5] The bias can, however, can be given an explicit form and, with some manipulation, it can be shown that the Solow residual is related to the underlying parameters of the problem by

$$\dot{A}^{S}_{it} = \lambda_{it} + [\epsilon_{it} - 1]\dot{K}_{it} - [\gamma_{it} + \epsilon^{B}_{it}]\dot{B}_{it} \tag{5}$$

where $\epsilon_{it} = \epsilon^{K}_{it} + \epsilon^{L}_{it} + \epsilon^{M}_{it}$ is the scale elasticity. This expression indicates that the growth rate of the measured Solow residual is the sum of three factors: (i) the rate of growth of public capital weighted by the indirect and direct contributions of public capital, (ii) the growth rate of private capital weighted by a correction for any error that is introduced by the assumption of constant returns to scale in private inputs, and (iii) the true growth rate of technical progress. Variants of (5) are also the basis for the marginal cost mark-up model of Hall (1988) and the externality model of Caballero and Lyons (1990a, 1990b).

Equation (5) relates the growth of the Solow residual to its component elements. However, since the goal of this paper is to examine the level of technical efficiency rather than its growth rate, one final step is needed to complete the second stage our analysis. By assuming that γ, ϵ, ϵ^B, and λ are constant over time, we can integrate (5) to obtain[6]

$$A^S_{it} = \ln A_{i0} + \lambda_i t + [\epsilon_i - 1]\ln K_{it} + [\gamma_i + \epsilon^B_i]\ln B_i \qquad (6)$$

A stochastic version of (6) in the empirical work presented below.

Equation (6) is expressed in continuous time. The empirical application of (6) follows requires the discrete time analogue developed by Jorgenson and Nishimizu, and extended by Denny, Fuss, and May (1981) and Christensen, Caves, and Jorgenson (1991). In this framework, the difference between the level of technology in region <u>i</u> at time <u>t</u> and region <u>j</u> at time <u>s</u> equals the logarithmic differences in output minus the share weighted logarithmic differences in inputs, where the shares are the simple averages of the shares in the two regions. The resulting levels indexes, A^S_{it}, are expressed relative to the efficiency of the "base" region in the base year, $A^S_{00}= 1$. We use the U.S total and 1970 as the base region and year, and thus all of the productivity index numbers should be interpreted as a proportion of national productivity in 1970.

III. Data

The data needed to estimate the parameters of equation (6) are described in full in our earlier papers (Hulten and Schwab (1984,1991). Our analysis is restricted to manufacturing industries, and most of our regional data are obtained from the Census of Manufactures and the Annual Survey of Manufactures and then reconciled to Bureau of Labor Statistics national totals. We use gross output as our measure of output in this paper, and thus our private inputs include capital, labor, and intermediate inputs (corrected for the purchased services problem). Since regional output deflators are not available from any source, we have used the national deflators from the U.S. Bureau of Labor Statistics. This introduces a potential bias in our results, since any error in the price deflator translates directly into an error in measuring real output and thus into an error in measuring the left hand side of (6).[7]

Our data on public capital are the same as those used in Munnell (1990), and a full description of the data are included in Appendix A of that paper. Briefly, Munnell used annual data on state capital outlays to allocate BEA estimates of the national stock of public capital among the states. Her data set includes estimates of total public capital for each state as well as separate estimates of state stocks of highways and water and sewer facilities. Since the Munnell data are available only for the period 1970-1986, our analysis is limited to those years.

Table 1 presents summary statistics on our measures of manufacturing input, output, and the Solow residual for the various regions, as well as statistics on regional output per worker, private capital per worker, and public capital. It is clear from this table that the manufacturing sector grew much faster in the South and West. Gross output rose 3.75 percent per year in the Sun Belt during the 1970-1986 period as compared to only 1.53 percent per year in the Snow Belt.[8] Labor input grew by more than 1 percent per year in the Sun Belt but fell in the Snow Belt. Public capital grew more rapidly in the Sun Belt (2.09 versus 1.30 percent).

It is apparent in the last two columns of Table 1 that regional differences in the growth rates of the Solow residual (TFP) were relatively small, while the trends in output, capital, and labor showed a strong convergence. Moreover, Table 1 indicates that the growth rates of capital per worker and output per worker were roughly the same in the Sun Belt and Snow Belt regions over this period. Our conclusions about the lack of TFP convergence during the years 1970-1986 can thus be extended to the convergence in output per worker due to capital-deepening.[9]

The last two rows of Table 1 present estimates of regional wage rates and rates of return to private capital. Inspection of this table indicates that the average manufacturing wage rate in the Sun Belt regions was less than the corresponding wage rate in the Snow Belt, while the average rate of return was persistently higher in the Sun Belt.[10] This is could be interpreted as evidence of a persistent disequilibrium in the factor markets. However, it should be noted that we have not standardized either the regional wage or rate of return for regional differences in industry mix, nor have we adjusted the wage for regional differences in the cost of living or skill differentials. Such adjustments might the eliminate the observed regional differentials, so this interpretation is at best a surmise.

We note, finally, that Table 1 covers a fairly short period 1970-1986, and it is possible that convergence (in terms of TFP or capital per worker) was essentially complete by that time. Regional gross output data are not available prior to the mid-1960s, but regional value added data are available beginning in 1951. In Table 2, we briefly shift the focus to value added as a measure of output in order to extend the analysis back in time. Out data show that there has been no significant compression (or divergence) in TFP, in output per worker, or in capital-deepening since 1951.

IV. Econometric Results

While the data shown in Tables 1 and 2 suggest that TFP levels in the various regions are approximately equal, they do not constitute a formal test of alternative hypotheses about regional growth. We carried out a standard econometric analysis by estimating the basic model (6) using ordinary least squares. This procedure yields the usual parameter estimates and hypothesis tests, but it is subject to a potential bias arising from the possibility that private capital (and possibly public capital as well) are endogenously determined by the level of TFP and may thus be correlated with the error term in the regression. However, the direction of the bias is unclear, since the feedback effect of TFP on capital formation may be positive or negative. Instrumental variables might be used to avoid simultaneous equations bias, but a set of valid regional instruments is hard to find.

Another problem arises from the fact that the estimation of the parameters of (6) produces an estimate of $\gamma+\epsilon^B$, so that these key parameters are not separately identified. However, since most public capital enters the production function of the manufacturing sector indirectly as a purchased intermediate good and not as a direct input, the elasticity ϵ^B is likely to be of negligible importance in manufacturing and can be assumed to equal zero, thus identifying the spillover parameter, γ.[11]

Our least squares estimates are reported in Table 3. The first column of that table shows the results obtained from the estimation of (6) under the assumption that the initial level of TFP and the growth rate of TFP are equal across regions (i.e., there are no regional fixed effects). Interestingly, the results are similar to those found in the earlier literature on public capital: the coefficient on public capital is statistically significant and reasonably large given that the direct effect of public capital is already accounted for in the purchased service component of the production function. The private capital coefficient suggests that there are mildly decreasing returns to scale and the point estimate of the time parameter implies a rate of TFP growth of 0.8 percent per year.

It is common in this literature to include a measure of capacity utilization in order to control for the cyclical effect of demand fluctuations on the Solow residual. We have followed this procedure in order to maintain comparability with other studies, even though there is no theoretical justification for including capacity utilization in a productivity model (Berndt and Fuss (1986), Hulten (1986)), and despite the fact that capacity utilization is particularly problematical in regional studies since regional capacity utilization measures are not available. Thus, column (5) in Table 3 adds the Federal Reserve Board's national capacity utilization data for manufacturing to the model in column (1). It is apparent that this does not change the picture very much, though the error-sum-of-squares does fall significantly.

One of the central results in the infrastructure literature is that the inclusion of regional fixed effects causes the estimated coefficient on infrastructure to become insignificant from zero (Holtz-Eakin 1991, Garcia-Mila, McGuire, and Porter 1992, Eisner 1991). In column (2) we allow for separate regional intercepts (New England is taken as the base region). As shown, the addition of these regional fixed effects causes the public capital spillover variable to become insignificant (and negative as well). Our finding are thus consistent with those of previous research. The estimated coefficient of private capital is also found to be statistically insignificant, implying constant returns to scale. Five of the regional intercepts are significant at conventional levels, and the rest are marginally significant at low levels. As before, adding capacity utilization does not change this picture, except to reduce the sum of squared errors and improve the significance of the regional intercepts.

Column (3) allows for regional time effects while holding the intercepts the same for all regions (i.e., we impose a common initial level of TFP to see if the time paths of TFP diverge). We find that this yields a larger estimate of the public capital spillover coefficient than the base case in column (1) and that it implies strongly decreasing returns to scale. Half of the regional time effects are significant. As before, adding capacity utilization does not change the results.

The last step taken in Table 3 is to go beyond the pure fixed effects model and allow both the intercepts and time coefficients to vary across regions. The results, shown in column (4), are consistent with the fixed effects model of column (2): the public and private capital variables are insignificant, half of the intercept dummy variables are significant, and none of the regional time dummies are significant. However, the addition of the capacity utilization variable does make a difference. When it is included, the public capital coefficient is significant and negative, implying that public capital externalities reduce TFP with an elasticity of -.24. This is a highly implausible result, and it casts doubt on the usefulness of using an aggregate capacity utilization adjustment.

Hypothesis Testing

The implied hypothesis tests of Table 3 can be generalized by putting them into a nested hypothesis testing framework. The nesting procedure is somewhat complicated from an expositional standpoint, since there are four sets of restrictions that are of interest, and these restrictions can be imposed one at a time, in pairs, three at a time, or all together. The four restrictions include:[12]

(1) the intercepts, interpreted as the levels of TFP in 1970, do not vary across regions (common productivity starting point).

(2) the time coefficients, interpreted as the growth rate of TFP, do not vary across regions (no convergence or divergence).

(3) the coefficient on public capital equals zero in all regions (no infrastructure spillovers).

(4) the coefficient on private capital equals zero in all regions (constant returns to scale).

The results of the various tests of the formally nested hypotheses confirm our basic conclusions. We found that the data do not reject any of the constraints imposed singly or in pairs. When we impose the restrictions three at a time, we find that we can reject the simultaneous equality of the initial levels of TFP (restriction (1)), a zero elasticity of TFP with respect to public capital (restriction (2)), and constant returns to the private inputs (restriction (3)). However, all of the other three-way restriction do hold jointly. Finally, the simultaneous imposition of all equality restrictions simultaneously is also rejected.

Some Econometric Extensions

We tested several variants of our models using several alternatives suggested in the infrastructure literature. Following Fernald (1992), we carried out an analysis of (6) using deviations from time trend rather than the log-level of variables in order to control for demand fluctuations and to reduce any simultaneous equation bias resulting from the endogeneity of public and private capital. The results of this exercise were similar to the results obtained using the capacity utilization variable.

We also tested the assumption of perfect competition using a Hall (1988) marginal cost mark-up model. In an imperfectly competitive market where the ratio of price to marginal cost is a constant μ, the income shares of labor and intermediate input are equal to the true output elasticities divided by μ (i.e., $\pi^L_{it} = \epsilon^L_{it}/\mu$ and $\pi^M_{it} = \epsilon^M_{it}/\mu$). If capital's share is calculated as a residual so the shares sum to one, then it follows from Hall's model that (6) becomes

$$(7) \qquad \ln A^S_{it} = \ln A_{i0} + \lambda_i\, t + [\gamma_i + \epsilon^B_{it}] \ln B_{it} + [\epsilon^B_{it} - 1] \ln K_{it} + (\mu - 1)\, [\pi^M_{it} \ln (M_{it}/ K_{it}) + \pi^L_{it} \ln (L_{it}/ K_{it})].$$

We estimate this model by adding the share-weighted log of the intermediate input-capital and the labor-capital ratios to the model underlying Table 3, thus obtaining an estimate of $(\mu - 1)$. Under perfect competition price equals marginal cost, μ equals 1, and the coefficient on $[\pi^M_{it} \ln (M_{it}/ K_{it}) + \pi^L_{it} \ln (L_{it}/ K_{it})]$ is zero; if firms have market power then price will exceed marginal cost and this coefficient will be positive.

Estimates of different versions of the Hall model are shown in Table 4. In those specifications where we exclude capacity utilization variable, our estimate of $(\mu - 1)$ is always positive and significant. This implies that the usual competitive pricing assumption of the Solow residual model is not appropriate, and non-competitive pricing must be taken into account (as in

(7)). However, our estimate of (μ - 1) is always insignificant in those specifications where we exclude capacity utilization variable, providing support for applying the competitive model to the measurement of TFP. Estimates of all of the other parameters in Table 4 are quite similar to the corresponding estimates in Table 3.

V. Summary and Conclusions

The key result of this paper is that the path of productive efficiency has been essentially parallel across regions in recent decades. This finding, which is consistent with our earlier work, suggests that manufacturing technology and organizational practice had already diffused widely throughout the country before the start of this period. By implication, this leaves little room for convergence explanations of regional growth that rely on the technological diffusion or learning-by-doing, or for endogenous growth explanations that rely on increasing returns to scale or the differential growth of public capital.[13] These alternatives have been widely discussed as mechanisms for explaining the convergence of output per capita in middle and high income countries, and while it was reasonable to postulate that they might be "imported" to explain the compression of regional incomes within the U.S., they do not seem to generalize in this way.[14]

What, then, does explain the pattern of regional manufacturing growth in the U.S.? Our results are consistent with a model of regional growth in which the location and scale of economic activity are strongly influenced by historical evolution and geographical factors: i.e., the U.S. developed from East to West, with the South initially specialized in agriculture, the North in commerce and manufacturing, and the Midwest, with its resource endowments, in manufacturing and agriculture. In this paradigm, the overall growth and structural changes in the economy (e.g., the huge increase in output per worker in the economy as a whole between 1880 and 1930, and the decline in the importance of the agricultural sector) unleashed forces that, at the level of regional economies, created significant factor market disequilibria: an excess supply of labor in the agricultural and resource regions of the South and West, but also opportunities for capital formation in those regions, which, in turn, raised the demand for manufacturing labor.

There is, however, an important caveat to this "explanation." Our finding that public capital <u>externalities</u> were not an important source of regional TFP differentials, but this does not mean that public capital formation is irrelevant. Indeed, it is likely to have played an essential role in facilitating the movement of capital, labor, and intermediate inputs among regions, and thus enabled the main sources of differential regional growth. The direct return to infrastructure investments may have been quite large, as Nadiri and Mamuneus (1995) found for the Interstate Highway System in the 1950s and 1960s. However, our results argue that excess returns due to spillovers are not an important component of the overall rate of return, at least for manufacturing industry, and therefore cannot be used to rationalize the very large rates of return to infrastructure found by Aschauer and others.

NOTES

1. The literature on infrastructure investment has grown voluminously since the papers by Aschauer (indeed, because of these papers). Gramlich (1994), Nadiri and Mamuneus (1995), and Pfahler et. al. (1996) provide extensive reviews of this literature.

2. See for example, Krugman (1990).

3. The formulation of technology also assumes that the spillover effect is separable from the pure technical effect, as represented by the parameter λ_i. This specification of the public capital externality also assumes that the only source of spillovers in each region is the quantity of public capital within that region. This implies, for example, that the highway system of one region may give rise to spillovers among manufacturing firms within the region, but the highways of an adjacent region have no effect at all. This is consistent with our interpretation of the region specific externalities as an engine of regionally endogenous growth.

4. This mode of analysis is termed "sources of growth analysis." For a review of the relevant literature, see U.S. Bureau of Labor Statistics (1983). It is worth noting, here, that the sources of growth analysis has, for the most part, ignored the role of public capital as a source of output growth.

5. This problem arises because the price of capital services, P^K_{it}, can rarely be observed directly. Capital income is usually imputed from the "adding-up" condition that factor payments exhaust total income, with capital income measured as the residual. The residual measurement of capital income thus imposes the condition that income shares sum to one (i.e., $\pi^K_{it} = 1 - \pi^L_{it} - \pi^M_{it}$). Thus whenever the elasticity of scale of private inputs $\epsilon_{it} = \epsilon^K_{it} + \epsilon^L_{it} + \epsilon^M_{it}$ is different from 1, π^X_{it} misstates capital's true output elasticity.

6. The constancy of these parameters imposes restrictions on the underlying technical efficiency terms of the production function (1). Note, however, that the multiplicative restrictions on the form of the efficiency function does not impose restrictions on the rest of the technology. In particular, they do not imply that the production function has the Cobb-Douglas form.

7. If the Law of One Price does not hold for manufactured goods within the U.S. market and there is in fact regional variation in output prices, our assumption of one price will overstate real output in those regions where prices are higher than average. This, in turn, overstates the level index of the Solow residual. If, in addition, the regional output prices are changing relative to the average, a bias is introduced into the growth rate of the Solow residual as well.

8. Throughout the paper, we define the Snow Belt as the New England, Middle Atlantic, East North Central, and West North Central Census divisions. The Sun Belt includes the South Atlantic, East South Central, West South Central, Mountain, and Pacific divisions.

9. This impression is reinforced by decomposing the total variation of TFP into variation across time within in regions and variation across regions. Slightly less than one-half of the variation in the level of TFP is due to cross sectional variation, with the balance due to variation over time. For the growth rates of TFP, however, virtually all of the variation is variation over time, i.e.there is almost no variation in the growth rate of TFP across regions. Given the

substantial differences in the growth rates of public capital stock in different regions, the lack of variation in the growth rate of TFP suggests that the two variables are essentially uncorrelated.

10. The internal rate of return in Table 2 is that rate such that, given the stock of capital, payments to factors of production exhaust revenue. Thus, as we noted above, this calculation assumes implicitly a constant returns to scale technology. We return to this issue in a subsequent section of the paper.

11. According to BLS data, trucks and autos accounted for approximately 8 percent of the income accruing to equipment in manufacturing, and thus about one percent of the total income, over the period 1949-83, and that communications and electricity generation equipment, which account for about 9 percent of income accruing to equipment, and, again, about one percent of total income. This low share reflects the fact that public capital is mainly an input to the transportation and communication sectors, to public utilities, and to some service industries, and these sectors pass along their services (and thus the services of public capital) by selling their output to manufacturing industries. Thus, public capital is at best a marginal contributor to the gross output of many such industries.

12. All of the models in Table 3 implicitly impose the restriction that the public and private capital elasticities are the same across regions, though not necessarily all equal to zero. Here we allow the public and capital coefficients to vary across regions unless we restrict these coefficients to equal zero.

13. E.g., Barro (1991), Baumol (1986), Baumol et. al. (1989), and De Long (1988).

14. Moreover, an inspection of the trends in output per worker and capital per worker for the 1970-86 and the 1951-86 periods using different output concepts does not offer any encouragement for the capital-deepening variant of the convergence hypothesis (Barro and Sala-i-Martin (1991), Holtz-Eakin (1991)).

Bibliography

Aschauer, David A. (1989). "Is Public Expenditure Productive?," Journal of Monetary Economics, 23, 177-200.

Aschauer, David A. (1990). "Why is Infrastructure Important?," in Alicia H. Munnell (ed.), Is There a Shortfall in Public Capital Investment?, Federal Reserve Bank of Boston, Boston, 21-50.

Barro, Robert J. (1990). "Government Spending in a Simple Model of Endogenous Growth," Journal of Political Economy, 98, Pt. 2, S103-S125.

Barro, Robert J. (1991). "Economic Growth in a Cross Section of Countries," The Quarterly Journal of Economics, 106, 407-443.

Barro, Robert J. and Xavier Sala-i-Martin (1991). "Convergence Across States and Regions," Brookings Papers on Economic Activity, No. 1, 107-158.

Baumol, William J. (1986). "Productivity Growth, Convergence, and Welfare: What the Long Data Show," American Economic Review, 76, 1072-1085.

Baumol, William J., Sue A.B. Blackman, and Edward N. Wolff, (1989). Productivity and American Leadership: The Long View, The MIT Press, Cambridge Massachusetts.

Berndt, Ernst R. and Melvyn A. Fuss (1986). "Productivity Measurement With Adjustments for Variations in Capacity Utilization, and Other Forms of Temporary Equilibrium," Journal of Econometrics, 33, 7-29.

Berndt, Ernst R. and Bengt Hansson (1992). "Measuring the Contribution of Public Infrastructure Capital in Sweden," The Scandinavian Journal of Economics, 94 (supplement), S151-S168.

Caballero, R. and R. Lyons (1990a). "The Role of Externalities in U.S. Manufacturing," NBER Working Paper No. 3033.

Caballero, R. and R. Lyons (1990b). "Internal and External Economies in European Industries," European Economic Review.

Christensen, Laurits R., Diane Cummings, and Dale W. Jorgenson (1981). "Relative Productivity Levels, 1947-1973: An International Comparison," European Economic Review, 16, 61-94.

De Long, J. Bradford (1988). "Productivity Growth, Convergence, and Welfare: Comment," American Economic Review, 78, 1138-1154.

Denny, Michael, Melvyn Fuss, and J.D. May (1981). "Intertemporal Changes in Regional Productivity in Canadian Manufacturing," Canadian Journal of Economics, 14, 390-408.

Dowrick, Steve and Duc-Tho Nguyen (1989). "OECD Comparative Economic Growth 1950-85: Catch-up and Convergence," The American Review, 79, 1010-1030.

Eisner, Robert (1991). "Infrastructure and Regional Economic Performance," New England Economic Review, Federal Reserve Bank of Boston, 47-58.

Fernald, John (1992). "How Productive is Infrastructure? Distinguishing Reality and Illusion with a Panel of U.S. Industries," Harvard University (unpublished).

Garcia-Mila, Theresa, Therese McGuire, and Robert H. Porter (1993). "The Effect of Public Capital in State-Level Production Functions Reconsidered," University of Illinois Institute of Government and Public Affairs Working Paper No. 24.

Gramlich, Edward M. (1994). "Infrastructure Investment: A Review Essay," _Journal of Economic Literature_, 32, no. 3, September, 1176-1196.

Hall, Robert E. (1988). "The Relation Between Price and Marginal Cost in U.S. Industry," _Journal of Political Economy_, 96, 921-947.

Holtz-Eakin, Douglas (1991). "Solow and the States: Capital Accumulation, Productivity and Economic Growth," Syracuse University working paper.

Holtz-Eakin, Douglas (1992). "Public Sector Capital and the productivity Puzzle," _Review of Economics and Statistics_, 76, 12-21.

Hulten, Charles R. (1986). "Productivity Change, Capacity Utilization and the Source of Efficiency Growth," _Journal of Econometrics_, 33, 31-50.

Hulten, Charles R. and Robert M. Schwab (1991). "Public Capital Formation and the Growth of Regional Manufacturing Industries," _National Tax Journal_, December, 121-134.

Hulten, Charles R. and Robert M. Schwab (1984). "Regional Productivity Growth in U.S. Manufacturing: 1951-1978," _American Economic Review_, 1984, 74, 152-162.

Jorgenson, Dale W. and Mieko Nishimizu (1978). "U.S. and Japanese Economic Growth, 1952-1874: An International Comparison," _The Economic Journal_, 88, 707-726.

Krugman, Paul R. (1990). "A 'Technology Gap' Model of International Trade," in Paul R. Krugman, _Rethinking International Trade_, Cambridge, MA, 152-164.

Lucas, Robert E. Jr. (1988). "On the Mechanics of Economic Development," _Journal of Monetary Economics_, 22, 3-42.

Meade, James E. (1952). "External Economies and Diseconomies in a Competitive Situation," _Economic Journal_, 62, 54-67.

Morrison, Catherine J. and Amy Ellen Schwartz (1991). "State Infrastructure and Economic Performance, Tufts University (unpublished).

Munnell, Alicia H. (1990). "How Does Public Infrastructure Affect Regional Economic Performance?," in Alicia H. Munnell (ed.), _Is There a Shortfall in Public Capital Investment?_, Federal Reserve Bank of Boston, Boston, 69-103.

Nadiri, M. Ishaq and Theofanis P. Mamuneas (1995), "Highway Capital Infrastructure and Industry Productivity Growth," (unpublished).

Pfahler, Wilhelm, Ulrich Hofman, and Werner Bonte (1996). "Does Extra Infrastructure Capital Matter? An Appraisal of Empirical Literature," _Finanzarchiv_, 68-112.

Rebelo, Sergio T. (1991). "Long-Run Policy Analysis and Long-Run Growth," _Journal of Political Economy_, Vol. 99, No. 3, 500-521.

Romer, Paul M. (1986). "Increasing Returns and Long-Run Growth," _Journal of Political Economy_, 94, 1002-1037.

Solow, Robert M. (1957) "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, 39, 312-320.

U.S. Bureau of Labor Statistics (1983). Trends in Multifactor Productivity 1948-81, Bulletin 2178, United States Government Printing Office, Washington.

Table 1
Summary of the Level and Growth Rate of Manufacturing Gross Output
1970-1986
(U.S. 1970 = 1.000)

	NE	**MA**	**ENC**	**WNC**	**SA**	**ESC**	**WSC**	**M**	**PAC**	**Total**	**Snow Belt**	**Sun Belt**
Gross Output												
1970	0.0590	0.1979	0.2767	0.0764	0.1234	0.0573	0.0780	0.0220	0.1094	1.0000	0.6100	0.3900
1986	0.0851	0.2106	0.3623	0.1212	0.2201	0.0978	0.1564	0.0428	0.1935	1.4897	0.7792	0.7105
Growth Rate	0.0229	0.0039	0.0169	0.0289	0.0362	0.0334	0.0435	0.0416	0.0357	0.0249	0.0153	0.0375
Labor												
1970	0.0773	0.2205	0.2620	0.0633	0.1325	0.0579	0.0618	0.0187	0.1053	1.0000	0.6227	0.3767
1986	0.0753	0.1626	0.2198	0.0684	0.1551	0.0628	0.0765	0.0310	0.1353	0.9868	0.5254	0.4611
Growth Rate	-0.0017	-0.0190	-0.0110	0.0049	0.0099	0.0050	0.0134	0.0314	0.0156	-0.0008	-0.0106	0.0126
Private Capital												
1970	0.0580	0.1890	0.2877	0.0552	0.1261	0.0597	0.0898	0.0199	0.1136	1.0000	0.5894	0.4106
1986	0.0902	0.2210	0.3456	0.1004	0.2122	0.0921	0.1727	0.0458	0.1995	1.4812	0.7571	0.7240
Growth Rate	0.0275	0.0098	0.0115	0.0374	0.0325	0.0271	0.0409	0.0521	0.0352	0.0246	0.0157	0.0354
Intermediate Input												
1970	0.0506	0.1838	0.2772	0.0859	0.1258	0.0578	0.0875	0.0245	0.1069	1.0000	0.5976	0.4024
1986	0.0640	0.1757	0.3428	0.1204	0.2003	0.0945	0.1677	0.0371	0.1722	1.3749	0.7030	0.6719
Growth Rate	0.0147	-0.0028	0.0133	0.0211	0.0291	0.0308	0.0407	0.0259	0.0298	0.0199	0.0102	0.0320
Total Factor Productivity												
1970	0.9113	0.9777	1.0192	1.1095	0.9576	0.9839	1.0226	1.0504	1.0202	1.0000	1.0027	0.9945
1986	1.1639	1.1966	1.2869	1.3137	1.2122	1.2285	1.2531	1.2069	1.2285	1.2386	1.2505	1.2251
Growth Rate	0.0153	0.0128	0.0146	0.0106	0.0147	0.0139	0.0127	0.0087	0.0116	0.0134	0.0138	0.0130
Labor Productivity												
1970	0.7630	0.8976	1.0561	1.2075	0.9315	0.9896	1.2630	1.1726	1.0383	1.0000	0.9795	1.0353
1986	1.1303	1.2948	1.6481	1.7721	1.4192	1.5572	2.0444	1.3815	1.4304	1.5096	1.4831	1.5409
Growth Rate	0.0246	0.0229	0.0278	0.0240	0.0263	0.0283	0.0301	0.0102	0.0200	0.0257	0.0259	0.0249
Capital Labor Ratio												
1970	0.7510	0.8570	1.0981	0.8724	0.9522	1.0307	1.4541	1.0622	1.0780	1.0000	0.9464	1.0899
1986	1.1984	1.3592	1.5719	1.4675	1.3687	1.4669	2.2570	1.4790	1.4745	1.5010	1.4411	1.5701
Growth Rate	0.0292	0.0288	0.0224	0.0325	0.0227	0.0221	0.0275	0.0207	0.0196	0.0254	0.0263	0.0228
Public Capital												
1970	0.0516	0.1820	0.1893	0.0847	0.1235	0.0620	0.0920	0.0497	0.1652	1.0000	0.5076	0.4924
1986	0.0645	0.2268	0.2219	0.1119	0.1949	0.0793	0.1364	0.0816	0.1959	1.3132	0.6251	0.6881
Growth Rate	0.0139	0.0138	0.0099	0.0174	0.0285	0.0154	0.0247	0.0310	0.0106	0.0170	0.0130	0.0209

Table 1 (continued)

Rate of Return												
1970	13.7%	14.8%	12.8%	19.7%	15.8%	19.7%	15.8%	17.5%	13.2%	15.9%	15.3%	16.4%
1986	8.5%	8.5%	8.5%	13.1%	13.6%	13.6%	8.7%	10.2%	7.5%	10.3%	9.7%	10.7%
Divisia Wage Index												
1970	0.955	1.016	1.097	0.979	0.851	0.842	0.924	0.962	1.103	0.970	1.012	0.937
1986	3.198	3.272	3.607	3.207	2.822	2.790	3.139	3.139	3.416	3.177	3.321	3.061

NE = New England, MA = Middle Atlantic, ENC = East North Central, WNC = West North Central, SA = South Atlantic, ESC = East South Central, WSC = West South Central, M = Mountain, PAC = Pacific

Table 2
Summary of the Growth Rate of Manufacturing Value Added
1951-1986

	NE	**MA**	**ENC**	**WNC**	**SA**	**ESC**	**WSC**	**M**	**PAC**	**Total**	**Snow Belt**	**Sun Belt**
Value Added	0.0258	0.0164	0.0215	0.0388	0.0451	0.0445	0.0473	0.0570	0.0445	0.0308	0.0222	0.0459
Labor	0.0002	-0.0074	-0.0026	0.0111	0.0190	0.0193	0.0238	0.0368	0.0230	0.0065	-0.0025	0.0219
Private Capital	0.0272	0.0183	0.0207	0.0370	0.0404	0.0428	0.0474	0.0526	0.0443	0.0309	0.0223	0.0442
Total Factor Productivity	0.0182	0.0166	0.0175	0.0197	0.0192	0.0173	0.0160	0.0538	0.0155	0.0171	0.0176	0.0170
Labor Productivity	0.0256	0.0238	0.0241	0.0277	0.0261	0.0252	0.0235	0.0202	0.0216	0.0244	0.0246	0.0240
Capital Labor Ratio	0.0270	0.0257	0.0233	0.0259	0.0213	0.0235	0.0236	0.0158	0.0214	0.0245	0.0248	0.0223

NE = New England, MA = Middle Atlantic, ENC = East North Central, WNC = West North Central, SA = South Atlantic, ESC = East South Central, WSC = West South Central, M = Mountain, PAC = Pacific

Table 3
Parameter Estimates of Alternative Restricted Models

	without adjustment for capacity utilization				with adjustment for capacity utilization			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	0.102214 (3.988)	-0.315016 (1.681)	0.126697 (3.533)	-0.660555 (2.037)	-0.378122 (3.880)	-0.910440 (5.912)	-0.351948 (4.979)	-1.42213 (5.846)
MA	--	0.174645 (2.133)	--	0.361255 (2.504)	--	0.223457 (3.579)	--	0.476241 (4.560)
ENC	--	0.245769 (3.015)	--	0.423950 (2.729)	--	0.283020 (4.558)	--	0.522270 (4.653)
WNC	--	0.200081 (5.137)	--	0.278372 (4.846)	--	0.227019 (7.635)	--	0.335459 (8.046)
SA	--	0.120506 (1.911)	--	0.215552 (2.253)	--	0.156855 (3.263)	--	0.288187 (4.163)
ESC	--	0.087153 (5.088)	--	0.127440 (4.225)	--	0.094803 (7.266)	--	0.140694 (6.466)
WSC	--	0.195922 (4.797)	--	0.245046 (4.018)	--	0.215640 (6.930)	--	0.288537 (6.542)
MT	--	0.060219 (1.591)	--	0.065613 (0.945)	--	0.078654 (2.728)	--	0.081865 (1.636)
PAC	--	0.191201 (2.653)	--	0.338488 (2.787)	--	0.237179 (4.313)	--	0.454201 (5.155)
Time	0.008445 (8.241)	0.010567 (7.225)	0.006314 (3.755)	0.015121 (5.448)	0.009906 (9.993)	0.012336 (10.959)	0.007492 (5.225)	0.016974 (8.461)
Time*MA	--	--	-0.002131 (0.859)	-0.005766 (1.976)	--	--	-0.001712 (0.814)	-0.005071 (2.412)
Time*ENC	--	--	0.007321 (3.439)	-0.003467 (1.235)	--	--	0.007512 (4.163)	-0.003097 (1.532)
Time*WNC	--	--	0.008035 (4.117)	-0.003878 (1.465)	--	--	0.008342 (5.041)	-0.003497 (1.833)
Time*SA	--	--	-0.002247 (1.058)	0.001049 (0.332)	--	--	-0.001937 (1.076)	0.003106 (1.359)
Time*ESC	--	--	0.004258 (2.824)	-0.002564 (0.987)	--	--	0.004339 (3.396)	-0.002015 (1.076)
Time*WSC	--	--	0.009938 (5.925)	0.002267 (0.746)	--	--	0.010056 (7.073)	0.003223 (1.472)
Time*MT	--	--	-0.000853 (0.393)	-0.002950 (0.867)	--	--	-0.000488 (0.266)	-0.001322 (0.538)

Time*PAC	--	--	0.001227 (0.520)	-0.004016 (1.515)	--	--	0.001630 (0.814)	-0.004545 (2.379)
Ln Public Capital	0.081694 (3.526)	-0.036604 (0.472)	0.158439 (4.704)	-0.117309 (1.034)	0.079613 (3.711)	-0.094269 (1.590)	0.150372 (5.263)	-0.244341 (2.961)
Ln Private Capital	-0.044530 (2.606)	-0.046562 (1.029)	-0.105826 (4.556)	-0.076725 (1.094)	-0.043099 (2.724)	-0.024187 (0.702)	-0.100638 (5.109)	-0.040135 (0.793)
Capacity Utilization	--	--	--	--	0.005806 (5.082)	0.005961 (10.191)	0.005731 (7.501)	0.006087 (11.150)
R^2	.3661	.7689	.6801	.7906	.4603	.8673	.7718	.8922
SSE	.53478	.19494	.26987	.17668	.45531	.11192	.19250	.09098
F-statistic	16.8480	1.7182	8.7689	--	33.0372	3.7976	18.4115	--

t statistics in parentheses

Table 4
Parameter Estimates of Hall Price Marginal Cost Model

	without adjustment for capacity utilization				with adjustment for capacity utilization			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	0.111867 (4.651)	-0.366781 (2.061)	0.131674 (3.744)	-0.501104 (1.604)	-0.287737 (2.999)	-0.89163 (5.803)	-0.332772 (4.504)	-1.435805 (5.641)
MA	--	0.198808 (2.556)	--	0.296728 (2.137)	--	0.228430 (3.673)	--	0.480014 (4.497)
ENC	--	.280831 (3.615)	--	0.360785 (2.417)	--	0.292247 (4.710)	--	0.525848 (4.602)
WNC	--	0.166374 (4.404)	--	0.222000 (3.903)	--	0.214389 (6.997)	--	0.338376 (7.582)
SA	--	0.136925 (2.287)	--	0.184615 (2.013)	--	0.160044 (3.344)	--	0.290149 (4.130)
ESC	--	0.091689 (5.638)	--	0.146818 (5.018)	--	0.095827 (7.375)	--	0.139978 (6.314)
WSC	--	0.215901 (5.538)	--	0.271294 (4.626)	--	0.220988 (7.098)	--	0.287790 (6.475)
MT	--	0.065067 (1.814)	--	0.119396 (1.760)	--	0.079134 (2.759)	--	0.079699 (1.547)
PAC	--	0.216643 (3.160)	--	0.314981 (2.712)	--	0.242739 (4.428)	--	0.456220 (5.122)
Time	0.011850 (9.893)	0.014131 (8.663)	0.008220 (4.575)	0.019052 (6.682)	0.012374 (10.858)	0.013394 (10.263)	0.008034 (5.162)	0.016821 (7.749)
Time*MA	--	--	-0.001958 (0.806)	-0.006045 (2.169)	--	--	-0.001675 (0.796)	-0.005053 (2.392)
Time*ENC	--	--	0.007331 (3.516)	-0.004480 (1.663)	--	--	0.007508 (4.158)	-0.003050 (1.492)
Time*WNC	--	--	0.006203 (3.052)	-0.004394 (1.735)	--	--	0.007768 (4.376)	-0.003472 (1.809)
Time*SA	--	--	-0.002491 (1.197)	-0.001665 (0.536)	--	--	-0.002023 (1.122)	0.003241 (1.348)
Time*ESC	--	--	0.004061 (2.748)	-0.005407 (2.084)	--	--	0.004276 (3.339)	-0.001888 (0.946)
Time*WSC	--	--	0.009572 (5.807)	-0.003909 (1.171)	--	--	0.009939 (6.957)	0.003497 (1.327)

Time*MT	--	--	0.000358 (0.165)	-0.005130 (1.555)	--	--	-0.000130 (0.069)	-0.001214 (0.480)
Time*PAC	--	--	0.001595 (0.689)	-0.006534 (2.495)	--	--	0.001729 (0.862)	-0.004441 (2.227)
$\Pi_{Man}(M/K)$ + $\Pi_{Ln}(L/K)$	.0260899 (4.737)	0.225726 (4.139)	0.144699 (2.652)	.247597 (3.732)	0.208365 (3.893)	0.073773 (1.579)	0.044449 (0.899)	-0.010626 (0.188)
Ln Public Capital	0.078704 (3.632)	-0.042892 (0.583)	0.150455 (4.542)	-0.083582 (0.769)	0.077584 (3.784)	-0.092869 (1.575)	0.148217 (5.166)	-0.246897 (2.941)
Ln Private Capital	-0.032747 (2.026)	-0.052971 (1.235)	-0.093573 (4.032)	-0.044749 (0.663)	-0.033935 (2.218)	-0.027622 (0.804)	-0.097066 (4.827)	-0.041188 (0.806)
Capacity Utilization	--	--	--	--	0.004806 (4.287)	0.005603 (8.977)	0.005520 (6.901)	0.006140 (9.959)
R^2	.4496	.7941	.6954	.8106	.5108	.8697	.7732	.8922
SSE	.46436	.17369	.25696	.15982	.41275	.10994	.19139	.09096
F-statistic	14.2204	1.2953	9.0718	--	28.9586	3.4161	18.0759	--

t statistics in parentheses

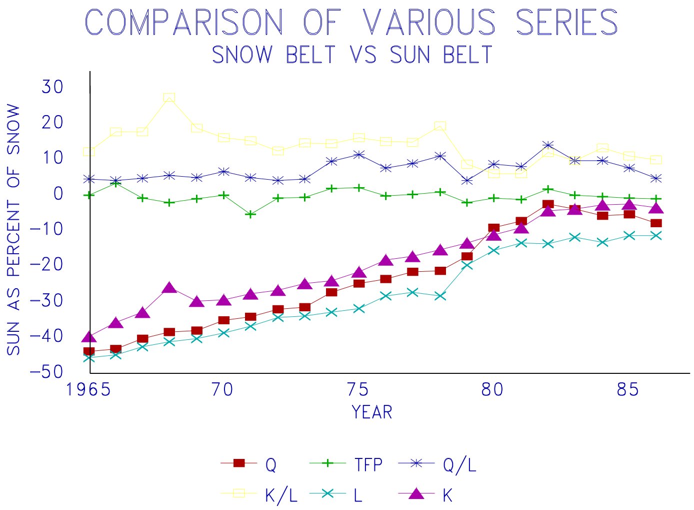

FIGURE 1

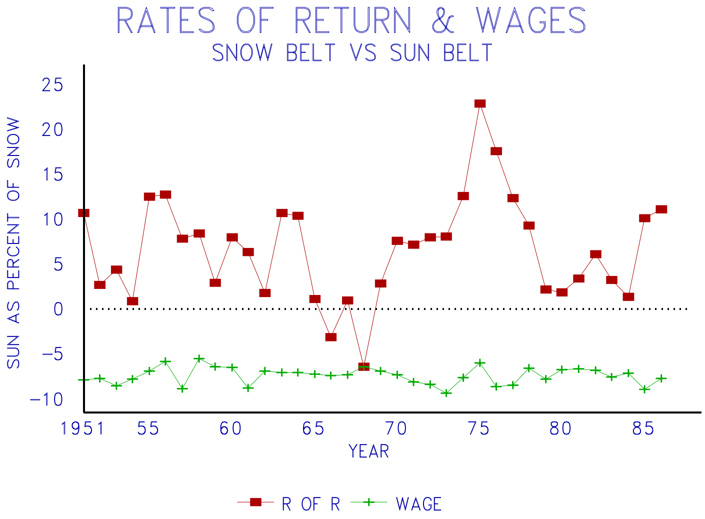

FIGURE 2