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Productivity and efficiency in the US: effects of business cycles and public capital

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Abstract

We add to the literature on the US productivity slowdown and effects of public capital on productivity by employing Malmquist productivity indexes to measure productivity. These indexes allow us to decompose productivity growth into efficiency change and technological innovation. We derive these components for each observation, which we exploit to explore factors which may lead to differences in productivity across regions, including business cycles, both own-state and cross-border public infrastructure investment, and relative sizes of the manufacturing, service and public sector. Our results suggest that the components of total factor productivity change lend important insights into the fairly complex effects of public capital on productivity growth.

Keywords: Productivity; Efficiency; Malmquist; Infrastructure; Spillovers

JEL classification: O47; H73

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1. Introduction

Over the last two decades considerable attention has been paid to the slowdown in productivity growth observed especially in the 1970s in the United States, both

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relative to past performance and in comparison to industrialized trading partners. While much evidence has been offered attesting to the magnitude of these events [see, for instance, Darby (1984), Litan et al. (1988), Kendrick (1980), Morrison (1992), Hulten and Schwab (1984) or Wolff (1996)] we still know very little about the causes of productivity changes.

One explanation that has received greater focus has been the coincident decline in infrastructure investment in the US overall. Hulten and Schwab (1991) apply a 'sources of growth' methodology to productivity growth and to estimate the impact of public capital. They find that productivity has a strong impact on economic growth in all regions of the US, but variations across regions are almost completely explained by differences in growth rates of private inputs. Thus, they find little, if any, explanatory power for infrastructure's impact on productivity growth. Similarly, Holtz-Eakin (1994) reports no discernible difference between regions in terms of public capital's effect on gross state product. In contrast, Aschauer (1989a–c) presents results that point to large, positive impacts of infrastructure investment on productivity. Also, Munnell (1990a,b) reveals a major role for public capital as a determinant of regional economic growth, with a particularly strong impact in the South.

Estimating translog production functions, Eberts (1986) and da Silva Costa et al. (1987) find positive effects of public capital, which were also found by Deno (1988) using a profit function approach.[1]

Perhaps the most sophisticated studies that employ state level data and address these issues are those of Morrison and Schwartz (1994, 1996a,b). All three studies employ a generalized Leontief cost function framework adapted to allow for quasifixed factors (private and public capital), which allows for short-run deviations from long-run equilibrium. They can identify these deviations through calculation of the shadow prices of the quasifixed inputs. They apply this approach to New England manufacturing states in their 1996a study, and to the 48 contiguous states in their 1994 and 1996b studies. They explicitly derive productivity effects in their 1996b study, and they too find positive direct productivity impacts of own public capital, but point out that these were often offset by the indirect effects.

Hulten and Schwab (1991) have noted that it is reasonable to expect that infrastructure investment in one region of a 'network' affects output in other regions of the network. They suggest that some means of accounting for public capital in other regions ''may be . . . more appropriate'' than simply incorporating only the 'target' region's infrastructure (p. 126). Regardless of whether we consider public goods to be pure or congestable the influence of infrastructure is

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[1] Some other studies which addressed the issue of the effect of public capital on economic performance, but do not assess regional effects, include Lynde and Richmond (1992), who analyzed the aggregate nonfinancial corporate sector in the US, and Shah (1992), who addressed this issue for the Mexican economy. Both of these studies estimated cost functions.

not likely to be confined within geopolitical boundaries. Holtz-Eakin and Schwartz (1994) have examined production when allowing for potential spillovers of the effects of highway capital stock across state lines and found that on average there is no statistically significant effect on productivity from either own-state or neighboring states' infrastructure investment.

The traditional growth accounting approach to computing productivity employs the assumption that observed factor income shares are equal to output elasticities, implying that factors are paid their marginal product, and that there is instantaneous adjustment to altered market conditions. To the extent that this does not hold then conventional estimates of Total Factor Productivity (TFP) change may be biased. In this case, firms may be technically or allocatively inefficient in the use of inputs. This, in turn, implies that observed input–output combinations may lie below the frontier of production technology. In such a case, TFP may change as a result of (dis)improved efficiency, that is, a movement (away from) towards the frontier. This is in contrast to the traditional growth accounting approach, which holds that observed output is equivalent to frontier output, and that growth in TFP is comprised only of technological progress, that is, shifts in the frontier.

In order to address some of these problems, Hulten (1986) and Berndt and Fuss (1986) modified the traditional productivity measures based on the growth accounting approach to allow for capacity underutilization that might result from sluggish adjustment by quasi-fixed inputs responding to changes in input prices. In the dual framework, this general idea is the rationale for using short-run variable cost functions, as in the Morrison and Schwartz papers. This allows for allocative inefficiency, but does not explicitly account for technical inefficiency. One could follow Bauer (1990), however, and specify the cost function as a stochastic frontier, allowing for both types of inefficiency.

In this paper, we follow Färe et al. (1994a,b) by adapting a technique that allows productivity growth to be decomposed into two mutually exclusive and exhaustive components: changes in technical efficiency over time, and shifts in the technology over time resulting from adoption of new techniques. In this study, the latter change reflects technical innovation as practised by 'state-of-the-art' firms, while the former represents (dis)improvement in the means by which known technology is applied in production.[2] We use the Malmquist total factor productivity index[3] and include own-state public infrastructure capital stock as an input to the production process. This approach allows us to disaggregate and decompose

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[2] Nishimizu and Page (1982) and Bauer (1990) have employed similar decompositions of TFP growth. The former estimate a single valued frontier production function, and the latter estimates a stochastic frontier cost function. Here we use multiple output distance functions to construct a Malmquist productivity index.

[3] Caves et al. (1982) developed this index and named it after Malmquist (1953), who had developed a similar quantity index based on distance functions in the consumer context. More recently, Domazlicky and Weber (1997), Domazlicky and Weber (1998) and Weber and Domazlicky (1999) have used the Malmquist index to examine total factor productivity.

the effects on productivity for each observation in the sample, not just average effects, which is a limitation of previous research. We can examine the characteristics of those states whose productivity levels are higher and that use their infrastructure investment more productively.

To this end, we consider several possible influences on productivity and its components. First, we investigate the effects of business cycles. Since it is reasonable to expect state economies to be neither perfectly in concert with nor independent of each other, then differences in productivity responses to cyclical fluctuations should be evident. In particular, states with higher growth rates are likely to exhibit tendencies for adoption of technical innovations, while regions with low or even declining growth may reveal efforts at improved efficiency. Second, variation across states in terms of the magnitude of the service sector relative to manufacturing may lead to different rates of technological adaptation and/or ability to efficiently utilize inputs. Third, differences across states in the ratio of private capital to labor might be expected to exert varying influences on efficiency and technical change. We hypothesize that states with higher capital-to-labor ratios will have a propensity towards using the latest, state-of-the-art technology and/or attaining maximal efficient use of inputs. Similarly, differences in the ratio of highway capital stock to private capital stock as well as the ratio of other forms of public capital to private capital may impart diverse effects on the components of productivity change. For instance, states with larger highway to private capital ratios might experience larger productivity impacts since private firms use the ‘free’ public good to augment production. Fourth, states with large private sectors relative to their total economy are hypothesized to be more efficient and experience greater technological innovation. Fifth, we consider Hulten and Schwab’s (1991) ‘network’ effect by measuring the impact of neighboring states’ highway capital on ‘home’ state productivity and efficiency.

2. The productivity index

The measure we use to analyze productivity performance of US state economies is the Malmquist productivity index. This index was introduced by Caves et al. (1982) as a theoretical construct based on distance functions. They showed that this index was equivalent (under certain conditions[4]) to the Törnquist index, which is the discrete counterpart of the Solow (1957) growth accounting model. The Törnquist index does not require estimation of distance functions. Instead, it aggregates inputs and outputs by weighting them by their shares. Unlike Caves, Christensen and Diewert, we follow Färe et al. (1989) (Färe, Grosskopf, Lindgren and Roos, hereafter FGLR), by calculating the Malmquist index directly, exploit-

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[4] These include: technology is translog, second-order terms are constant over time, firms are cost minimizers and revenue maximizers.

ing the fact that the distance functions upon which the Malmquist index is based can be calculated as reciprocals of Farrell (1957) technical efficiency measures. As shown in FGLR, this allows the decomposition of productivity into changes in efficiency (catching up) and changes in technology (innovation).

More formally, if there are $x^t = (x_1^t, \ldots, x_N^t)$ inputs at period $t = 1, \ldots, T$ that are used to produce outputs $y^t = (y_1^t, \ldots, y_M^t)$, then the technology at t consists of all feasible (x^t, y^t), i.e.

$$S^t = \{(x^t, y^t): x^t \text{ can produce } y^t\} \tag{1}$$

The output distance function is due to Ronald Shephard (1970) and is defined[5] relative to the technology S^t as

$$D_o^t(x^t, y^t) = \min\{\theta: (x^t, y^t/\theta) \in S^t\}, \quad x^t \in \mathbb{R}_+^N, \quad t = 1, \ldots, T \tag{2}$$

Given x^t, the distance function increases y^t as much as possible (by scaling it by θ) while remaining in S^t. We note that there is a close relationship between the distance function and the Farrell output based measure of technical efficiency. Specifically:

$$\begin{aligned} D_o^t(x^t, y^t) &= \min\{\theta: (x^t, y^t/\theta) \in S^t\} \\ &= [\max\{\theta: (x^t, \theta y^t) \in S^t\}]^{-1} \\ &= 1/F_o^t(x^t, y^t) \end{aligned}$$

where $F_o^t(x^t, y^t)$ is the Farrell output based measure of technical efficiency (Farrell, 1957).

To illustrate the construction of the technology S^t from observed data, we borrow a simple example from Färe et al. (1997). Suppose that one input is used in the production of one output and that there are two observations A and B, described by the following data:

	A	*B*
x	2	5
y	3	5

B uses more inputs than *A* to produce more output, but *B*'s average productivity (y/x) is lower, i.e. $y^A/x^A = 3/2 > y^B/x^B = 1$. The reference technology is created from both observations, but the frontier is formed by the observation with the highest average product, firm *A*, as depicted in Fig. 1. Since *A* is the best practice firm here, under constant returns to scale, *B* is compared to *A* in terms of average

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[5] See Färe (1988) for a detailed discussion of input and output distance functions.

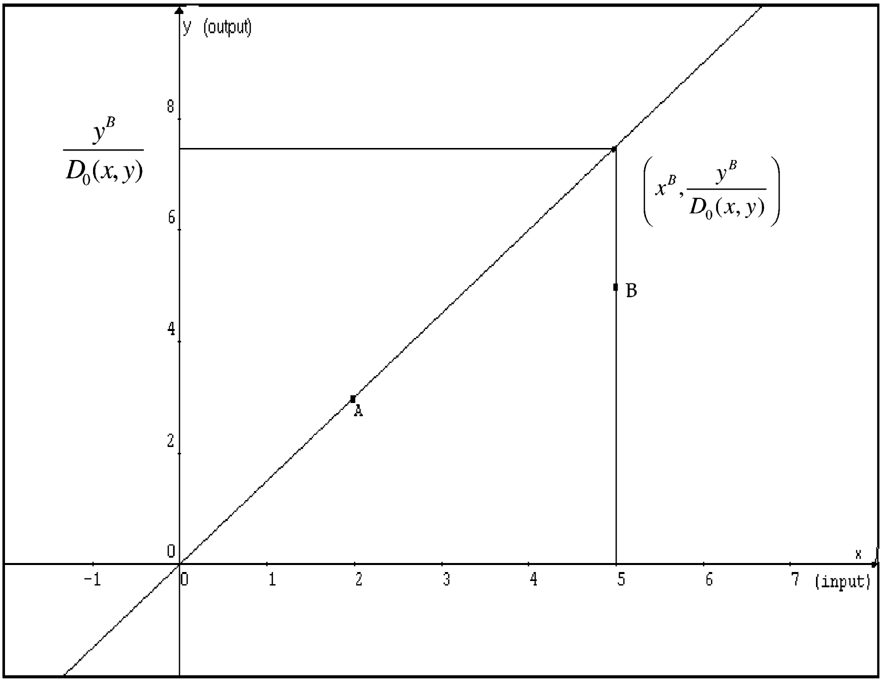

Fig. 1. The distance function and best practice frontier.

product. Thus, the value of the distance function for B will be the ratio of observed to maximum potential output

$$D_o(x^B, y^B) = 2/3$$

since,

$$\frac{y^{*B}}{x^B} = \frac{5/D_o(x^B, y^B)}{5} = 3/2 = \frac{y^A}{x^A}$$

where $y^{*B} = y^B/D_o(x^B, y^B)$, i.e. maximum potential output. Also note that $D_o(x^A, y^A) = 1$.

The Malmquist productivity change index computed here is based on the simple idea illustrated above, but it allows comparisons between two periods. Again, distance functions are used to provide a measure of deviations from maximum average product. Specifically, following FGLR, we define the Malmquist index of productivity change as[6]

$$M_{\mathrm{o}}^{t,t+1} = \left[\frac{D_{\mathrm{o}}^{t+1}(x^{t+1}, y^{t+1})}{D_{\mathrm{o}}^{t}(x^{t}, y^{t})} \frac{D_{\mathrm{o}}^{t}(x^{t+1}, y^{t+1})}{D_{\mathrm{o}}^{t+1}(x^{t}, y^{t})} \right]^{1/2} \tag{3}$$

As shown by FGLR, this index can be decomposed into two components: efficiency change and technological change, as defined below:

$$\text{Efficiency Change } (EC) = \frac{D_{\mathrm{o}}^{t+1}(x^{t+1}, y^{t+1})}{D_{\mathrm{o}}^{t}(x^{t}, y^{t})} \tag{4}$$

$$\text{Technological Change } (TC) = \left[\frac{D_{\mathrm{o}}^{t}(x^{t+1}, y^{t+1})}{D_{\mathrm{o}}^{t+1}(x^{t+1}, y^{t+1})} \frac{D_{\mathrm{o}}^{t}(x^{t}, y^{t})}{D_{\mathrm{o}}^{t+1}(x^{t}, y^{t})} \right]^{1/2} \tag{5}$$

or

$$M_{\mathrm{o}}^{t,t+1} = EC \cdot TC \tag{6}$$

We calculate the component distance functions of the Malmquist index using programming methods which are equivalent to the nonparametric methods used in data envelopment analysis (DEA).[7] This technique constructs a ‘grand’ frontier based on the data from all of the observations in the sample, sometimes referred to as the best practice frontier. As illustrated in Fig. 1, the best practice frontier is determined by the observations with the highest average product or productivity. Each observation is compared to that frontier. How much closer an observation gets to the frontier is dubbed catching up; how much the frontier shifts at each observation’s observed input mix is due to technical change or innovation. The product of these two components yields a frontier version of productivity change. Since these can be calculated without using expenditure or price data, confounding price and quantity changes over time can be avoided. The linear programming problems we compute are included in Appendix B. [Appendix A shows cluster information for each state.]

3. Data and model specification

The Malmquist index is based on distance functions that are specified in terms of input quantities and output quantities. In intuitive terms, they are a multiple

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[6] See also Färe et al. (1994a,b) for a more accessible exposition of the Malmquist index and the technique used here to calculate it.

[7] See Charnes et al. (1978).

output generalization of a production function. We would like to specify a fairly general technology, one in which a state's own public infrastructure can be included as an input.

We use the same data as Munnell (1990a,b), which is a panel of 48 states (Hawaii and Alaska are excluded) over the 1970–1986 period. Although our model could accommodate multiple outputs, the data we use has a single output, namely gross state product. The inputs we use include the value of own-state public capital stock [see Appendix A of Munnell (1990a) for details], the value of private sector capital and nonagricultural employment. Again, our model does not require specification of variables in value terms; the data were constructed in those terms. All monetary values are in 1982 dollars.[8]

Thus, our component distance functions include a measure of aggregate output, and three input variables, one of which is used to capture public sector effects. We use mathematical programming to construct the technology and compute the individual distance functions necessary to construct the Malmquist index. The index is computed for each state for every pair of adjacent time periods, t and $t+1$. Each state is compared to the portion of the 'grand frontier' that most closely resembles its own mix of inputs and output. The frontier is determined by the best practice observations in the sample.

The average annual productivity indexes and components are reported in Table 1 for each state and for each year in Table 2. These represent the geometric means of productivity change from 1970 to 1986 for Table 1, and the geometric mean across all states in each year for Table 2. Values greater than one indicate improvements; values less than one reflect declines in performance. For 37 states mean EFFCH (efficiency change) exceeds one, indicating there is greater output from given inputs. *TC* (technical change) is greater than one for 31 states, suggesting that some states did not benefit from production enhancing techniques. For instance, New Mexico experiences improved efficiency on average, but fails to maintain 'state-of-the-art' technology. The lagging performance in technical change outweighs improvements in efficiency such that overall productivity fell on average during the sample period. Conversely, Florida records diminished efficiency, but overall productivity growth due to advancement in technological capacity. As a further example, Illinois simultaneously experiences positive efficiency change and negative technical change that, on net, yields constant productivity. These examples clearly illustrate the advantages of a decomposable productivity measure: in our case, states perform differently in terms of their ability to adapt to change. Since these are averages, even greater variation is observed on a year-to-year basis.

Table 2 gives a summary of average annual changes by year. Here we have

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[8] There is an implicit assumption that the prices of goods are the same across states. To the extent that a state's output is produced and sold in national markets at relatively uniform prices (or sold locally at national prices), this assumption will not be problematic.

Table 1
Average annual changes, 1970–1986[a]

State	MALM	EFFCH	*TC*
Alabama	1.0084	1.0066	1.0018
Arizona	1.0017	1.0020	0.9997
Arkansas	1.0114	1.0101	1.0012
California	1.0063	1.0000	1.0063
Colorado	1.0069	1.0003	1.0065
Connecticut	1.0062	1.0003	1.0059
Delaware	1.0057	1.0000	1.0057
Florida	1.0080	0.9944	1.0137
Georgia	1.0097	1.0028	1.0069
Idaho	1.0035	1.0033	1.0003
Illinois	1.0009	0.9954	1.0055
Indiana	1.0056	1.0035	1.0021
Iowa	1.0063	1.0068	0.9995
Kansas	0.9982	1.0006	0.9976
Kentucky	1.0007	1.0003	1.0005
Louisiana	0.9853	1.0000	0.9853
Maine	1.0138	1.0055	1.0082
Maryland	0.9970	0.9953	1.0016
Massachusetts	0.9950	0.9989	0.9961
Michigan	1.0028	0.9992	1.0036
Minnesota	1.0071	1.0059	1.0012
Mississippi	1.0070	1.0062	1.0008
Missouri	1.0061	1.0003	1.0058
Montana	1.0001	1.0080	0.9922
Nebraska	1.0029	1.0056	0.9974
Nevada	1.0033	1.0033	0.9999
New Hampshire	1.0231	1.0107	1.0123
New Jersey	1.0040	1.0000	1.0040
New Mexico	0.9979	1.0029	0.9950
New York	0.9959	1.0000	0.9959
North Carolina	1.0114	1.0027	1.0086
North Dakota	0.9992	1.0104	0.9888
Ohio	1.0040	0.9975	1.0065
Oklahoma	0.9965	0.9985	0.9980
Oregon	1.0033	1.0007	1.0026
Pennsylvania	1.0039	0.9979	1.0059
Rhode Island	0.9322	1.0000	0.9322
South Carolina	1.0077	0.9999	1.0078
South Dakota	1.0041	1.0087	0.9954
Tennessee	1.0132	1.0100	1.0032
Texas	1.0038	1.0000	1.0038
Utah	1.0075	1.0038	1.0036
Vermont	1.0104	1.0000	1.0104
Virginia	1.0009	0.9981	1.0028
Washington	1.0014	1.0018	0.9995
West Virginia	0.9842	0.9915	0.9926
Wisconsin	1.0098	1.0039	1.0059
Wyoming	0.9807	1.0000	0.9807

[a] These are the average annual changes in the indexes over the 1970–1986 period, computed as the geometric mean of the adjacent pair indexes.

Table 2
Average annual changes, 1970–1986

Year	MALM	EFFCH	*TC*
1970–71	0.9981	1.0007	0.9974
1971–72	1.0140	1.0043	1.0097
1972–73	1.0127	1.0143	0.9984
1973–74	0.9611	1.0037	0.9575
1974–75	0.9656	0.9946	0.9708
1975–76	1.0217	0.9944	1.0275
1976–77	1.0210	0.9969	1.0151
1977–78	1.0185	1.0047	1.0137
1978–79	0.9983	0.9996	0.9987
1979–80	0.9769	0.9884	0.9983
1980–81	1.0116	1.0268	0.9852
1981–82	0.9784	0.9986	0.9798
1982–83	1.0169	0.9985	1.0184
1983–84	1.0350	1.0048	1.0310
1984–85	1.0122	0.9961	1.0162
1985–86	1.0009	1.0054	0.9955

taken the (unweighted) geometric means of our measures across states for each pair of years. The post oil shock periods show declining productivity (as expected), generally reflected in declines in both technical change and efficiency change. Again, these averages mask considerable variations at the disaggregated level, which we analyze next in a regression framework.

In order to analyze productivity growth we regress each of our change in productivity measures, Eqs. (3)–(5), on several explanatory variables. First, we are interested in knowing whether boom periods impact productivity differently than recessionary periods. We construct two dummy variables that reflect the business cycle. If a state's growth in GSP is greater (less) than one standard deviation from the mean growth rate, the BOOM (RECESSION) variable takes a value of one. Second, improvements in productivity should be conditioned on the level of productivity from which the change occurred. The variable EFFICIENCY is calculated by means of Eq. (3). It allows us to measure the effect that the initial level of productivity has on changes in the various components of productivity as well as for productivity itself. This can be done for each state, in each year. Third, to control for the variation in the relative importance of different sectors we include the ratio of service to manufacturing GSP (Service/Manufacturing), as well as the ratio of private capital to labor (Private Capital/Labor). Fourth, in an attempt to identify which, if any, form of public sector spending is important to productivity growth we include various measures of the relative importance of private and public sector capital, and of the private sector share. Given the predominant evidence discussed above that public sector spending has little or no impact on growth, our hypothesis is that public sector spending has no impact on productivity. Thus, we expect negative coefficients for the ratio of highway capital to private capital (Highway/Private Capital), the ratio of public capital to private capital (Public Capital/Private Capital), and neighboring state's public sector capital (Neighbors[9]). In the same vein, the private sector share of GSP (Private Share) would be positively related to productivity change.

Several studies attempt to measure differences in productivity across regions. Although it is not our intent to delve into that topic we do consider it necessary to account for possible similarities of characteristics of states within regions and differences between regions when we undertake our regression analyses. To that end we classify 'members' of a region on the basis of two alternative definitions of region. One is the familiar four US census regions: East, North Central, South and West. The second is comprised of a clustering of the states based on private sector share of GSP and growth in GSP. This type of clustering follows the argument made in Case et al. (1993) that state policies and growth may be influenced not by neighboring states or geographically close jurisdictions, but rather 'peer' states, i.e. those states with similar socio-demographic characteristics and government structures and size.

Ideally we would like to estimate the model allowing for structure of regional dependence. A 'full-information' technique would be SUR. However, our sample has too short a time series relative to the cross-sectional data, which implies that the estimated disturbance covariance matrix would be singular [see Gunther and Schmidt (1993) for details]. A parsimonious alternative would be to adopt a spatial autocorrelation structure [an example would be Case et al. (1993)]. However, a specific structure must be chosen. If the structure is incorrect, indiscernible specification bias would result. To avoid assuming a spatial structure, we adopt a block covariance structure, which provides the necessary parsimony in the covariance structure but is akin to the full information approach in that little structure is placed on the assumed linkages across cross-sections. This approach requires that we define the states to be included in each region or block. We use the two definitions described above. Using this error structure we estimate a model with fixed state effects for the Malmquist index and its two components separately. Thus, we interpret each coefficient as referring to the effect of the corresponding independent variable on 'average' state productivity change.

The results displayed in Table 3(a)–(c) are quite similar for both definitions of regional blocks. Furthermore, in all estimations the assumption of a diagonal

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[9] This was constructed from the data available in Munnell on the stock of highways in each state. We use the weighted sum of the state highways contiguous to a given state, where the weight is the area of each respective state.

Table 3
Parameter estimates

Variable	Clusters			
	Census regions		Private sector share	
	Parameter estimate	Standard error	Parameter estimate	Standard error
(a) Malmquist index				
Boom	0.024	0.0003	0.025	0.0002
Recession	−0.039	0.0003	−0.040	0.0003
Productivity level	−0.261	0.0072	−0.267	0.0071
Service/manufacturing	0.007	0.0012	0.006	0.0007
Private capital/labour	−0.0002	0.0001	−0.0002	0.00009
Highway/private capital	0.011	0.023	−0.022	0.0071
Neighbors	0.021	0.003	0.022	0.003
Public capital/private capital	0.219	0.012	0.239	0.011
Private sector share	0.710	0.034	0.697	0.0242

Variable	Clusters			
	Census regions		Private sector share and GSP growth	
	Parameter estimate	Standard error	Parameter estimate	Standard error
(b) Efficiency change index				
Boom	0.009	0.0001	0.0089	0.00003
Recession	−0.008	0.0001	−0.0081	0.00005
Productivity level	−0.414	0.0128	−0.4115	0.0027
Service/manufacturing	0.007	0.0006	0.0075	0.00027
Private capital/labor	−0.0001	0.00005	−0.0001	0.00001
Highway/private capital	0.249	0.016	0.2487	0.0033
Neighbors	−0.0008	0.0019	−0.0027	0.0027
Public capital/private capital	0.073	0.0093	0.0839	0.0027
Private sector share	0.846	0.0202	0.8571	0.0075
(c) Technical change index				
Boom	0.015	0.00004	0.0153	0.0002
Recession	−0.033	0.00005	−0.0325	0.0003
Productivity level	0.103	0.0009	0.1032	0.0037
Service/manufacturing	0.002	0.0001	0.0029	0.0007
Private capital/labor	−0.00006	0.00001	−0.00009	0.00007
Highway/private capital	−0.197	0.0055	−0.2004	0.0052
Neighbors	0.011	0.0007	0.0143	0.0037
Public capital/private capital	0.138	0.0024	0.1272	0.0089
Private sector share	−0.073	0.0018	−0.0767	0.0139

covariance matrix is rejected at any reasonable level of significance. For the RECESSION variable the coefficients are negative and highly significant for all components of productivity. Thus, not only does productivity decrease, but (firms in) states respond by becoming less efficient in the use of resources [see Table 3(b)]. This is to be expected given idle capital and labor hoarding during an economic downturn. Similarly, during a recession firms exhibit diminished propensity to adopt new technology [see Table 3(c)]. Negative coefficients do not necessarily imply a decrease in technological capacity. However, they do imply a decrease in the rate of technical innovation.[10]

When states experience a boom period of economic expansion, productivity improves, as we would expect. From the results reported in Tables 3(b) and (c) it is evident that during booms there is greater productivity due to improved efficiency as well as positive technical change.

There is evidence of productivity convergence when examining the relation between the Malmquist index and the initial level of productivity. Those states with higher initial levels of productivity had smaller increases in Malmquist productivity. This result appears to be driven by the efficiency aspects of productivity. The relatively large negative coefficient in Table 3(b) indicates that states with lower initial levels of productivity experience more rapid improvement in efficiency. Contrarily, the technical change component of productivity was lower for states with low levels of productivity, implying that states with low levels of productivity were less likely to be driving technological advancement. In other words, sites that were technologically ‘ahead’ were more likely to embrace innovations and push the production frontier outwards. Our evidence confirms the intuition that technology ‘leaders’ continue in their role by adopting state-of-the-art technology, while ‘followers’ improve their productivity by incorporating already existing technology.

The regression results also indicate that the rate at which technical innovation, efficiency and overall productivity advance is higher in states with service sectors that are large relative to manufacturing. This may be due, in part, to the dramatic growth in the service sector during the sample period. For the Malmquist index, productivity is higher in states with larger service sectors and lower where capital intensity is higher. There is some support for saying that both technical and efficiency change contribute to this.

Focusing on those variables that measure public sector capital, we find some

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[10] Interpretation of the regression coefficient estimates is the same as that for any (state) fixed effects model, with one qualification. The dependent variables measure the relative position of a state’s input–output mix from one time period to the next. As such, these index values indicate percentage change. Thus, a coefficient value of, say, 0.02 represents a 2% increase (on average) from the previous position.

new evidence concerning the relation between public sector investment and productivity. The decomposition of the productivity measures substantially aids this analysis. In Table 3(a), the coefficient on Highway/Private Capital is not statistically significant. However, the corresponding coefficient value in Table 3(b) is positive and significant, indicating that highway capital is important to the efficiency change component; contrarily, that the coefficient in Table 3(c) is negative and significant, suggesting a negative impact of relatively more highway capital on technical change. The implication here is that a higher proportion of highway capital allows (firms in) states to more efficiently utilize available technology, but it does not add to the technological capacity of the state.

Neighboring states' highway public capital is important to overall total factor productivity, but there is a different effect on the efficiency and technical change components. The impact of Neighbors' highway capital is important to improving the technical change measure of productivity, but is unrelated to efficiency change.

The remaining measure of public sector capital, Public Capital/Private Capital, is uniformly positive and significant in all regressions. Contrary to recent articles that suggest a negative relationship between public capital and output, our results indicate that the larger public capital stock is relative to private sector capital stock the greater the positive impact on changes in productivity, efficiency and technical innovation.

We also include a measure of the size of the private sector. Again the importance of the decomposition is evident. Our measure of total factor productivity is higher when private sector share of GSP is higher. Not surprisingly, the efficiency change is also positively influenced by a higher private sector share. Increases in productivity due to technical change are lower in states where private sector share is higher. Thus, states with larger (relative) public sectors experience greater technical change.

4. Conclusion

Measuring productivity change by means of a decomposable Malmquist index allows closer examination of two underlying foundations that shape productivity change. Since the values of the efficiency and technical change components are reported for each observation the results can be further examined for factors that contribute to variation across observations.

In doing so, we have found that during recessions productivity decreases as a result of both diminished efficiency and reduced technical innovation. During booms it is both improved efficiency and greater innovation that lead to increased productivity. Other results include: the size of the service sector relative to manufacturing is, in general, an important determinant of productivity growth;

states with higher ratios of private capital relative to labor experience lower levels of productivity growth; states with relatively larger private sectors are more efficient but less likely to innovate; and there is evidence that public capital does have an impact on private sector productivity. However, that impact will not be uncovered without use of a decomposable measure. For instance, highway capital appears to not have an effect [see Table 3(a)], but this is due to the offsetting impacts of the components of productivity change [Tables 3(b) and (c)].

Our results for neighborhood spillover effects are not in complete agreement with those reported by Holtz-Eakin and Schwartz (1994) and Kelejian and Robinson (1994). The latter authors use various specifications of the Cobb–Douglas production model to account for econometric issues (state-specific fixed effects, spatial correlation and endogeneity of inputs) that arise in consideration of the effect of own-state and neighboring states' highway capital on production. In general, they find that only in the most simplistic models can support be offered for public capital spillovers. Conversely, in econometrically 'more correct' models the impact is either statistically insignificant or negative.

We find that neighboring states' highway capital contributes to productivity growth. However, the components of productivity change indicate that neighbors' capital has a positive effect on technical change, but an insignificant negative effect on efficiency change. In comparing these results, keep in mind that the above-mentioned authors estimate marginal effects of neighbors' capital on output, whereas we directly estimate the effect of such capital on the comparative static performance of states — namely, productivity change and its components.

To sum up, we view this paper as providing an alternative and complementary approach to analyzing economic performance and the determinants of that performance. Our approach resembles that of Morrison and Schwartz as well as other studies that allow for short-run inefficiency and impose very little structure on technology. It differs from their work in that we take a primal approach, use nonparametric estimation methods and explicitly identify efficiency change and technical change components at the state level.

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Appendix A

State	Clusters	
	Census region	Private sector share and GSP growth
Alabama	3	1
Arizona	4	5
Arkansas	3	2
California	4	2
Colorado	4	1
Connecticut	1	2
Delaware	3	3
Florida	3	5
Georgia	3	1
Idaho	4	2
Illinois	2	4
Indiana	2	4
Iowa	2	4
Kansas	2	3
Kentucky	3	3
Louisiana	3	4
Maine	1	2
Maryland	3	6
Massachusetts	1	2
Michigan	2	4
Minnesota	2	2
Mississippi	3	2
Missouri	2	3
Montana	4	3
Nebraska	2	3
Nevada	4	5
New Hampshire	1	5
New Jersey	1	2
New Mexico	0	1
New York	1	4
North Carolina	3	2
North Dakota	2	2
Ohio	2	4
Oklahoma	3	3
Oregon	4	2

Pennsylvania	1	4
Rhode Island	1	3
South Carolina	3	1
South Dakota	2	3
Tennessee	3	2
Texas	3	2
Utah	4	1
Vermont	1	2
Virginia	3	6
Washington	4	1
West Virginia	3	4
Wisconsin	2	2
Wyoming	4	4

Appendix B

To calculate technical change and efficiency change we compute distance functions for the following type: for each state, $k=1,\ldots,K$ and period $t=1,\ldots,T$,

$$
\begin{aligned}
[D(x^{k',t}, y^{k',t})]^{-1} = & \max_{(\theta,z)} \theta \\
& \text{s.t. } \theta y_m^{k',t} \leq \sum_{k=1}^{K} z^{k,t} y_m^{k,t}, \quad m=1,\ldots,M \\
& \sum_{k=1}^{K} z^{k,t} x_n^{k,t} \leq x_n^{k',t}, \quad n=1,\ldots,N \\
& z^{k,t} \geq 0, \quad k=1,\ldots,K
\end{aligned}
\tag{9}
$$

where y is output (in our case a scalar, i.e. $M=1$), and x_n is the vector of nonspillover inputs.

The z's and the θ are variables for which we solve. The z's serve the purpose of constructing the reference technology as convex combinations of the data. The inequalities allow for the usual assumption of strong (or free) disposability of outputs and inputs.

The other three components are calculated similarly, substituting the appropriate period data (i.e. t or $t+1$).

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