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U.S. Total Factor Productivity Slowdown: Evidence from the U.S. States

by Roberto Cardarelli and Lusine Lusinyan

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U.S. Total Factor Productivity Slowdown: Evidence from the U.S. States

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Abstract

Total factor productivity (TFP) growth began slowing in the United States in the mid-2000s, before the Great Recession. To many, the main culprit is the fading positive impact of the information technology (IT) revolution that took place in the 1990s. But our estimates of TFP growth across the U.S. states reveal that the slowdown in TFP was quite widespread and not particularly stronger in IT-producing states or in those with a relatively more intensive usage of IT. An alternative explanation offered in this paper is that the slowdown in U.S. TFP growth reflects a loss of efficiency or market dynamism over the last two decades. Indeed, there are large differences in production efficiency across U.S. states, with the states having better educational attainment and greater investment in R&D being closer to the production "frontier."

JEL Classification Numbers: O47, E23, O30, R11

Keywords: Productivity, growth, stochastic frontier analysis, U.S. states

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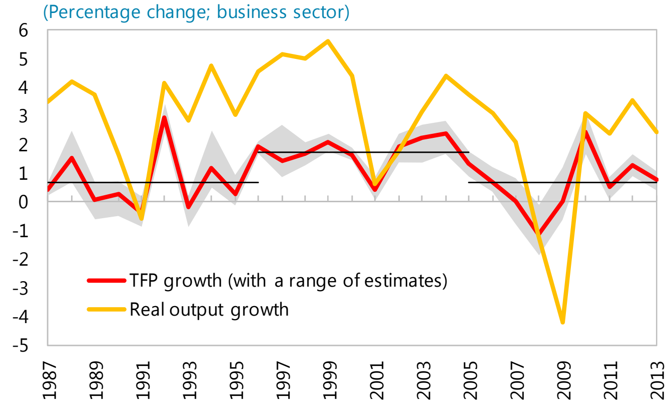
Contents

I. Productivity Slowdown: The Debate

U.S. total factor productivity growth has slowed since mid-2000s. After growing at about 1¾ percent per year during 1996–2004, average total factor productivity (TFP) growth rate has halved since 2005 (Chart). This suggests that the reasons of the slowdown go beyond the effects of the Great Recession. Understanding what is driving the slowdown is key to assessing the future potential growth of the U.S. economy (CEA, 2014).

United States: TFP and Real Output Growth

(Percentage change; business sector)



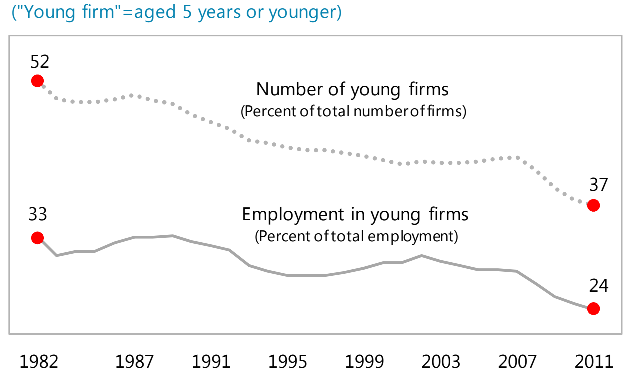
Sources: BLS; OECD; Fernald (2014); and IMF staff estimates.

Some argue that the slowdown in TFP growth reflects the reduced ability of the U.S. economy to benefit from technological advances. Gordon (2012 and 2013) suggests that technological innovation has become marginally less important for growth. Fernald (2014) argues that the recent subdued pace of productivity growth is merely the return to more normal rates following nearly a decade of extraordinary gains from the information technology (IT) revolution. A few others are more optimistic on the room for technology to keep boosting TFP growth in the future, as they see still room for positive knockout effects from past technological advances, especially in services (e.g., Baily, Manyika, and Gupta, 2013; Byrne, Oliner, and Sichel, 2013), or are confident on the continuing transformational nature of recent IT innovations (Bernanke, 2013).

But TFP growth depends on many factors besides advances in technology. In general, TFP captures the efficiency with which labor and capital are combined to generate output. This depends not only on businesses' ability to innovate, but also on the extent to which they operate in an institutional, regulatory, and legal environment that fosters competition, removes unnecessary administrative burden, provides modern and efficient infrastructure, and allows easy access to finance (for a literature survey, see for example, Syverson, 2011, and Isaksson, 2007).[2] A few authors suggest that the slowdown in U.S. TFP growth reflects a more secular loss of market "dynamism" given the importance of business churning,

United States: The Declining Share of Young Firms

("Young firm"=aged 5 years or younger)



Sources: U.S. Census Bureau Longitudinal Business Database 1977-2011; and IMF staff calculations.

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[2] In practice, TFP is usually obtained as a residual in estimates of a production function, once the contributions from measured inputs have been estimated. Thus, growth in output not directly attributable to changes in labor and capital would be captured in TFP, including unobserved factor utilization and measurement errors.

"creative destruction", business startups, and young firms (Chart) to generate productivity gains though more efficient resource allocation and greater innovation (e.g., Haltiwanger, 2011). Furthermore, Haltiwanger, Hathaway, and Miranda (2014) show that the decline in firm formation and entrepreneurship has been especially pronounced in the high-tech sector after 2002. The decline in dynamism is also evident in the U.S. labor market, with slower geographic mobility and labor turnover only partly reflecting population aging and a higher share of older firms (Hyatt and Spletzer, 2013; and Tarullo, 2014).[3]

The objective of this chapter is to shed light on the slowdown of U.S. TFP growth using evidence from TFP estimated across U.S. states over the last two decades. In particular, we focus on three main questions:

- *Has the TFP growth slowdown been similar across U.S. states?* Fernald (2014) and earlier studies (Bauer and Lee, 2006; Daveri and Mascotto 2006) look at *labor productivity*, which captures cross-state variation of both TFP and capital deepening. Most likely reflecting data limitations, little is known about state-level TFP developments in recent years.[4]

- *To what extent can aggregate U.S. TFP growth benefit from low-productivity states converging to high-productivity ones?* Higher aggregate TFP growth can be achieved by shifting the production frontier outward (through technological innovations) for all states, but also by closing the gap between the "frontier" and "laggard" states (by tackling inefficiencies that prevent all states to be on the production frontier). Identifying relative contributions of these factors to TFP growth would provide further insights to productivity prospects and policy options.

- *Can we exploit the variation of TFP growth and its main determinants across the U.S. states to speculate on what factors and policies are most important for TFP growth*? To the extent that the cross-sectional (across U.S. states) variation in TFP experiences allows us to robustly identify a few key factors associated with TFP growth, these could be the focus of policy actions.

Our results suggest that TFP growth in the United States can benefit especially from policies that promote investment in human capital and research and development. We find that the slowdown in TFP growth from mid-2000s has been widespread across the U.S. states and does not seem to be stronger in those states which rank higher in terms of production or usage of IT. Our analysis suggests that the TFP slowdown across the U.S. states owes more

[3] Hyatt and Spletzer (2013) argue that while the decline in employment dynamics is concentrated in recession periods, from which it has never fully recovered, it remains an open empirical question whether the decline indicates increasing labor market adjustment costs or better job matching.

[4] Blanco, Prieger, and Gu (2013) and Caliendo and others (2014) are notable exceptions but they do not cover the period after 2007, and while the former focuses primarily on the impact of research and development, the latter examines aggregate implications of disaggregated (by region and sector) productivity changes and the role of regional trade. Sharma, Sylwester, and Margono (2007) look at sources of state-level TFP growth over the period of 1977–2000.

to a declining efficiency in combining factors of production than to a diminishing pace of technological progress. We find that higher educational attainment, greater spending on research and developments (R&D), and a larger financial sector are associated with lower "inefficiencies" across U.S. states. Our analysis of TFP determinants across U.S. states over the last two decades suggests that human capital is a significant factor associated with TFP growth.

II. Empirical Analysis

Our empirical analysis is carried out in three stages. First, we estimate state-level TFP growth using a standard Cobb-Douglas production function with time-varying and state-specific labor shares. Second, we use a stochastic frontier analysis to assess the relative contributions to TFP growth from common technological trends and state-specific technical efficiency. Third, we analyze the determinants of TFP growth across U.S. states using panel data models that relate TFP growth to human capital, innovation, infrastructure, taxation, and regulatory framework.

There are a number of important caveats to analyzing TFP trends at U.S. state level.[5] In particular, there is no data on capital stock or services for U.S. states. We use data from Garofalo and Yamarik (2002) and Yamarik (2013), who start from the net national capital stock at the industry level (from the Bureau of Economic Analysis; for each one-digit industry including services and agriculture) and allocate it to individual states' industries based on their share of national industry income.[6] This approach assumes that the capital-to-output ratio within each industry is the same across U.S. states, which could lead to an underestimation of TFP in states where capital productivity is high, and therefore may imply understating the actual variation in TFP across states. Also, our labor input variable is employment in the private sector, rather than hours worked: this means that changes in labor utilization (that is, in hours per worker) would be included in our TFP estimates. The accurate measurement of TFP is an exercise traditionally fraught with measurement errors and goes beyond the objectives of this chapter.[7] Rather, our main objective is to exploit the variation in our TFP estimates across U.S. states to assess whether they are significantly associated with a few underlying factors that have traditionally been related to TFP growth.[8]

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[5] For details on data sources and description, see Appendix 1.

[6] For example, Sharma, Sylwester, and Margono (2007), LaSage and Pace (2009), and Blanco, Prieger, and Gu, (2013) use capital stock data constructed by Garofalo and Yamarik (2002) and Yamarik (2013), while Turner, Tamura, and Mulholland (2013) construct alternative series of state-level physical capital covering 1947–2001, which show very high correlation with the Garofalo-Yamarik series (for further discussion, see also Panda, 2010).

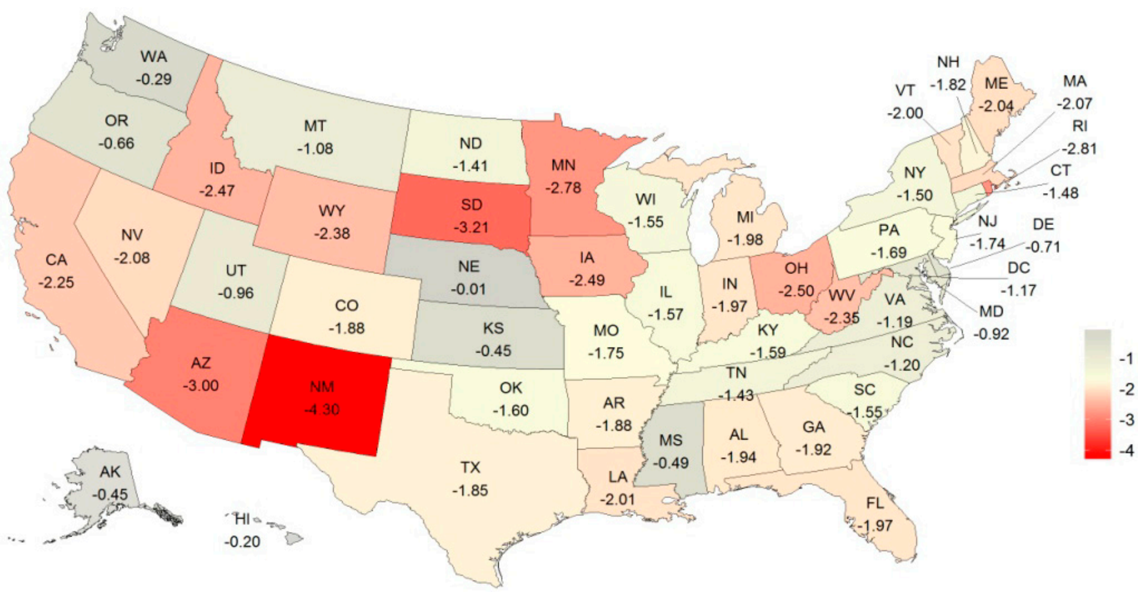
[7] See, for example, Hauk and Wacziarg (2009) for a discussion of measurement error in growth regressions.

[8] Two different robustness checks support our TFP estimates: first, the GDP-weighted average of state TFP growth follows very closely national aggregate TFP growth estimates from a range of sources (including BLS). Second, our state TFP growth estimates are strongly correlated with those from Caliendo and others (2014) who construct state-level TFP by aggregating industry-level TFP estimates using the industry (revenues) shares within each state as weights.

A. Is Productivity Growth Different Across U.S. States?

The slowdown in TFP growth after mid-2000s has been widespread across U.S. states, but there have also been some significant differences (Figure 1, Appendix Figure A1). While for the U.S. as a whole the TFP growth slowed about 1¾ percentage points on average in 2005–2010 relative to 1996–2004, the state-level estimates range from a decline of over 3 percentage points in New Mexico and South Dakota to a relatively modest (below 1 percent) decline in ten states, with Oregon standing as a clear outlier in terms of a sustained high pace of TFP growth over the whole period (Appendix Figure A2).

Figure 1. Deceleration in Average TFP Growth, 2005–2010 vs. 1996–2004
(Percentage change)

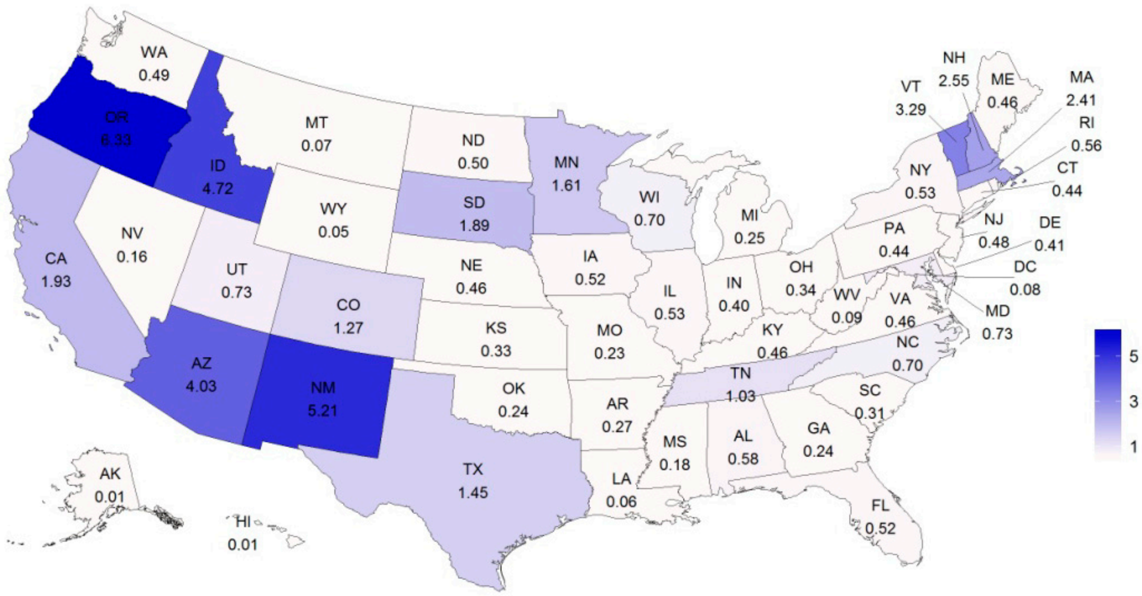


Source: IMF staff estimates.

Figure 2. IT Specialization Across U.S. States

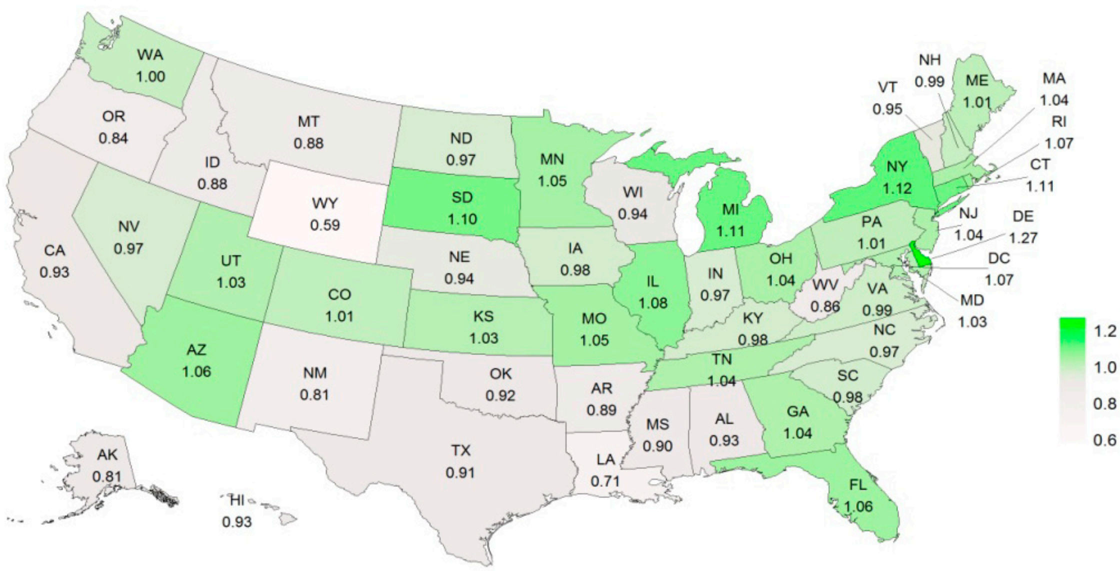
IT Producing States

(Index; U.S.-wide output share of IT-producing industries in total private industries=1)



IT-Intensive Using States

(Index; U.S.-wide output share of IT-using industries in total private industries=1)



Source: IMF staff estimates.

There is little evidence that the TFP growth slowdown was significantly higher in those states which are most intensively producing or using information technology. We measure the extent to which a state is specialized in IT production and the degree to which it uses IT given its industry composition and industry-level IT-intensity estimates (see Appendix 1). Figure 2 shows the two measures of IT-specialization prior to the productivity slowdown, and suggests that IT production was more geographically concentrated across U.S. states than IT usage (as in Daveri and Mascotto, 2006). A series of statistical tests (similar to Stiroh, 2002, and Daveri and Mascotto, 2006) using various measures of IT-specialization show no significant additional TFP deceleration for IT-producing or IT-intensive states relative to other states (see Appendix 2, Tables A1 and A2). In particular, the two states—New Mexico and Oregon—with the highest degree of specialization in IT-production and a similar degree of IT-intensity had very different productivity and growth outcomes.

B. Technological Progress vs. Efficiency

An alternative way to analyze TFP growth is to decompose it more explicitly into contributions from technological progress and improvement in efficiency. Following the common approach in the stochastic frontier analysis (SFA), we assume that inefficiencies potentially drive a wedge between actual production and the production frontier, given the existing state of technology (Box 1). In this framework, technological progress (proxied by a time trend) shifts the production frontier upward for all states, while an improvement in technical efficiency (captured by state-/time-specific variables) moves states towards the production frontier.[9]

[9] Using SFA with a translog production function, Sharma, Sylwester, and Margono (2007) decompose TFP growth for the lower 48 U.S. states over the period 1977–2000 and show that TFP growth mainly stemmed from technological progress, while differences in efficiency change explained cross-state differences in TFP. Oil and coal producing states underwent the greatest declines in efficiency, while those with larger financial sectors experienced greatest increases. Also, human capital, urbanization, and shares of non-agriculture and financial sectors were positively associated with efficiency. Jerzmanowski (2007) also finds that the TFP growth in the U.S. between 1960 and 1995 was entirely due to the growth of technology while the average efficiency change was zero.

Box 1. Stochastic Frontier Analysis

For a given state *s*, assume

$$Y_{st} = f(X_{st}, t)\theta_{st}e^{v_{st}}$$

where Y is output of the state, $f(\cdot)$ is production function of inputs X and technological change *t*, $\theta \in (0,1]$ is the level of efficiency, with $\theta = 1$ indicating that the state is achieving the optimal output with the technology embodied in the production function $f(\cdot)$, and e^{v} is a random shock. For a log-linear production function with two inputs (labor and capital), a time trend to proxy a common technology, and $u_{st} = -\ln(\theta_{st})$ denoting inefficiency, such that

$$y_{st} = \beta_0 + \beta_L x_{L,st} + \beta_K x_{K,st} + \beta_t t + v_{st} - u_{st}$$

the point estimates of technical efficiency (TE) can be derived via $E[exp\{-u_{st}|\varepsilon\}]$, where $\varepsilon = v_{st} - u_{st}$ is the model error term comprised of the two independent, unobservable error terms. The coefficient $\widehat{\beta_t}$ on the time trend represents the change in the frontier output caused by technological change. Furthermore, Kumbakhar and Lovell (2000) show that a change in TFP, defined as output growth unexplained by input growth, can be expressed as

$$\Delta TFP = \Delta T + \Delta TE + (\epsilon - 1)\left[\frac{\epsilon_L}{\epsilon}\Delta x_L + \frac{\epsilon_K}{\epsilon}\Delta x_K\right]$$

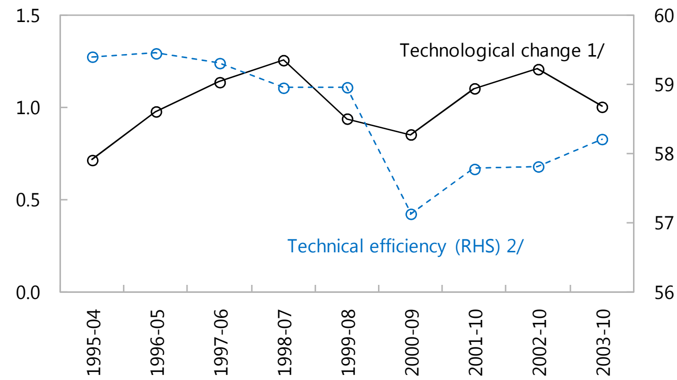
where $\Delta T = \widehat{\beta_t} = \frac{dy}{dt}$ is technological change, $\Delta TE = -\frac{du}{dt}$ is change in technical efficiency, and $\epsilon_L(\epsilon_K)$ output elasticities with respect to labor (capital), with $\epsilon = \epsilon_L + \epsilon_K$ specifying returns to scale ($\epsilon = 1$ is the case of constant returns to scale).

Specifications for u_{st} vary, and in our analysis, we use two versions of time-varying inefficiency (having looked at other specifications as well, including time-invariant inefficiency and "true" fixed-effects models, see, Belotti and others, 2012).

- Time-varying inefficiency with convergence (or decay specification): $u_{st} = exp\{-\eta(t - T_s\}u_s$, where T_s is the last period in the *s*th panel, and η is the decay parameter, such that when $\eta > 0$, the degree of inefficiency decreases over time (i.e., converges 'down' towards the base level of inefficiency in the last period $t = T_s$), and when $\eta < 0$, the degree of inefficiency increases over time.
- Time-varying conditional inefficiency: $u_{st} = z_{st}\delta + w_{st}$, where z_{st} is a vector of explanatory variables associated with technical inefficiency of production in state *s*. Parameters of the stochastic frontier and the model for the technical inefficiency effects are simultaneously estimated with a maximum likelihood method (Battese and Coelli, 1995).

Our results show that technological change has been relatively stable, while technical efficiency has slowed. Rolling-window estimates of the SFA model over the period 1995–2010 suggest that the production frontier has been shifting up at a relatively constant rate of about 1 percent per year (the solid black line in Chart), close to the estimates found in the literature (e.g., Jerzmanowski, 2007) (Appendix 2, Table A3). The estimated technical efficiency declined over time, with the average state moving slightly away from the frontier (the dashed blue line in the Chart).[10]

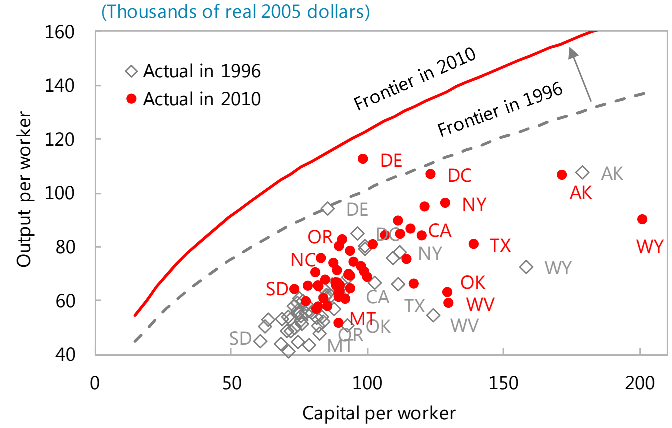
U.S. States: Sources of TFP Growth



Source: IMF staff estimates.
1/ Growth rate; 2/ average actual output in percent of production frontier.

There is, however, large variation in efficiency rates across states. On average, over the whole period, Delaware was found to be quite close to the production frontier, while Oklahoma, West Virginia, and Montana were those furthest away from it (Chart and Appendix Figure A3). Staff estimates that if all states with lower-than-average efficiency converged to the average efficiency, average aggregate output per worker would have been about 3 percent higher than its actual level in 2010.

Production Frontier, 1996 vs. 2010
(Thousands of real 2005 dollars)



Source: IMF staff estimates.

Investment in human capital and R&D appear to reduce estimated inefficiencies. Using an SFA model which allows for conditional inefficiency effects (Battese and Coelli, 1995), we test whether we can attribute the variation in inefficiency across states to differences in a number of productivity-friendly underlying factors (Appendix 2, Table A4).[11] We find statistically significant and robust results showing that states with greater human capital (as proxied by years of schooling, especially elementary and tertiary educational attainment) tend to be have smaller inefficiencies.[12] A greater share of total R&D spending in GDP also tends to lower inefficiencies, in addition to (potentially) contributing positively to technological progress. Possibly reflecting the role of financial intermediation in resource allocation, states with a larger financial sector tend to

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[10] Technical efficiency estimates are on a lower side of the estimates found in the literature for the U.S. states: for example, mean efficiency in Sharma, Sylwester, and Marganon (2007) is estimated at 76 percent.

[11] Note that this exercise is looking at the factors that may explain the shortfall of actual output from production frontier which may or may not be the same factors that are associated with TFP growth discussed in the following section, since TFP growth includes changes in both technical efficiency and production frontier.

[12] In particular, a one year increase in average years of schooling is associated with about 10 percent decrease in technical inefficiency.

be more efficient. In the following section, we test the impact of these factors on TFP growth within a panel data framework.

C. Determinants of State-Level TFP Growth

There is a vast empirical literature on the many factors that can affect TFP growth. (e.g., Isaksson, 2007). Our focus here is on whether the variation of TFP growth across U.S. states over the last two decades can be associated with cross-state variation in education, R&D and innovation, infrastructure, tax policies, and other institutional and regulatory characteristics. To investigate these relationships, we use a number of econometric specifications, including fixed-effects regressions with three-year averages and a mean group model, which allows for parameter heterogeneity and cross-sectional dependence.[13]

Our results confirm the previous findings that investment in human capital and R&D/innovation are important factors associated with TFP growth (Appendix 2, Table A5). In particular:

- ***Education***. The average years of schooling in the U.S. increased from 13.1 in 1996 to 13.8 in 2010 (albeit slowing in 2004–06), but substantial variation remains across states: the average years of schooling vary from below 12.5 years in Mississippi and West Virginia to over 14.5 years in the District of Columbia and Massachusetts. We find a strong positive relation between the indicator of human capital and TFP growth.
- ***R&D and innovation***. Total R&D expenditure in the U.S. was about 2½ percent of GDP per year in 1996–2010, about three-quarters of which performed by business sector. Business R&D has however been declining (as share of GDP) in 2000–05 and at 2 percent of GDP in 2012 is close to its 2000 peak. New Mexico has the highest total (7.5 percent of GDP) and government (4.4 percent of GDP) R&D spending, while the highest business R&D is in Michigan (4.2 percent of GDP). We find some support for a positive impact of both business R&D expenditure and, more importantly, of government R&D spending and TFP growth. Including interaction terms for both types of R&D expenditure, however, makes their combined effects statistically insignificant.

III. Conclusions

Our analysis of TFP trends across U.S. states suggests that there is scope for policies to tackle inefficiencies and help boost productivity. In particular, our findings show that the slowdown in TFP has not been confined to IT-producing or IT-intensive user states, and if anything, the estimated pace of technological progress has remained broadly unchanged since mid-1990s. Instead, there are signs of increasing inefficiencies and slower catching-up, which may be associated with divergence in educational attainment and R&D spending.

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[13] As part of robustness tests, we have also estimated fixed-effects model with five-year averages, dynamic panel data models using system-GMM estimator, and various modifications to the specifications reported in Appendix 2, Table A5, including to control for the impact of possible outliers.

While mindful of the differences between empirical associations and causal relations, these findings suggest that policies that promote investment in human capital and innovation may boost aggregate TFP growth.

Appendix 1. Data Sources and Description

Output: Gross domestic product by state in chained (2005) dollars private industries is from the BEA. Data on NAICS–based private (and total) industries for 1997–2012 are extended backwards by splicing with SIC-based series for 1987–1997. Private industries account on average for more than 85 percent of total gross state product.

Labor input: Employment in the private sector is constructed as the sum of farm employment and private nonfarm employment from the BEA. Data on NAICS–based private (and total) industries for 1990–2012 are extended backwards by splicing with SIC-based series for 1987–1989.

Capital input: Net private capital stock data by state, in chained 2005 dollars, are from Yamarik (2013) up to 2007, with the extension for 2008–2010 provided by the author. Yamarik (2013) tests the soundness of the state-level capital and investment (derived from capital stock through the perpetual inventory method) data by estimating a Cobb-Douglas production function and a Solow growth model and finds that estimates of the output elasticity for capital are plausible and close to the national income share. Net private capital stock for the United States is from BEA (rebased from 2009 to 2005 as a base year).

Labor and capital shares: Following Gomme and Rupert (2004) and Blanco, Prieger, and Gu (2013), labor share of GDP is the ratio of private sector compensation of employees to the difference between private sector output and 'ambiguous labor income'. The latter is the sum of taxes-less-subsidies and proprietor income. To smooth the series, a three-year moving average of the labor share is used. Capital share is one minus labor share.

IT-producing states: Specialization in IT-production is assessed as the share of IT-producing "Computer and electronic product manufacturing" industry (NAICS code 334) in total private industries in a given state *s* relative to the same share for the U.S. as a whole. In particular, a synthetic index following Daveri and Mascotto (2006) is constructed as $Index_i^s = \left(\frac{Y_i^s}{Y^s}\right) / \left(\frac{Y_i}{Y}\right)$, where

Y_i^s is the output in sector i in state s, Y^s is total private industries' output in state s, Y_i is the U.S. total output in sector i, and Y is total U.S. output in private industries. A state is characterized as "IT-producing state" if the value of the index is bigger than or equal to one. Following Stiroh (2002), in order to obtain an exogenous indicator of specialization prior to the productivity slowdown, the index is calculated as the average of 2002–04.

ICT-producing states: Specialization in ICT-production is assessed as the share of NAICS-composite "Information, Communication, and Technology" sector in total private industries in a given state *s* relative to the same share for the U.S. as a whole. ICT aggregate includes primary ICT sectors (directly involved in manufacture of ICT equipment, software, services, repair, etc.) and secondary sectors that indirectly or partially involved in ICT industry activities or significantly dependent on ICT industries. For the construction of the synthetic index, see above.

IT-intensive user states: IT-intensity is assessed as the share of the sectors identified in Jorgenson, Ho, and Samuels (2010, Table 1) in total private industries in a given state *s* relative to the same share for the U.S. as a whole. IT-using industries are those with more than the median share of IT-intensity index, defined in turn as the share of IT-capital input (and IT services purchased) in total capital input of a given industry. For the construction of the synthetic index, see above, except the reference year here is 2005 reflecting data availability in Jorgenson, Ho, and Samuels (2010).

Educational attainment: Average years of schooling. The main data source, Turner et al. (2006) has been extended after 2000 with the data from the OECD Regional Database using elementary (6 years), secondary (12 years) and tertiary (20.52 years) attainment series to calculate the average years of schooling. The data for the total U.S. are from the Census "Table A-1. Years of School Completed by People 25 Years and Over, by Age and Sex: Selected Years 1940 to 2012."

Innovation indicators (R&D expenditure): The OECD Regional Database for state-level data on R&D expenditure by sector, R&D personnel by sector, employment in high-tech sectors, patent applications (by sector) and ownership. The data are annual covering the period of 1990–2010/2011. The original data source is the U.S. National Science Foundation (NSF)/Division of Science Resources Statistics (SRS).

Infrastructure: State and local government expenditure on infrastructure (as a share of GDP), including spending on highway and air transportation, housing, water, and sanitation, from Sorens, Muedini, and Ruger (2008).

Tax burden: Tax burden is state and local revenues from all taxes (but not current charges), as a percentage of personal income, from Sorens, Muedini, and Ruger (2008).

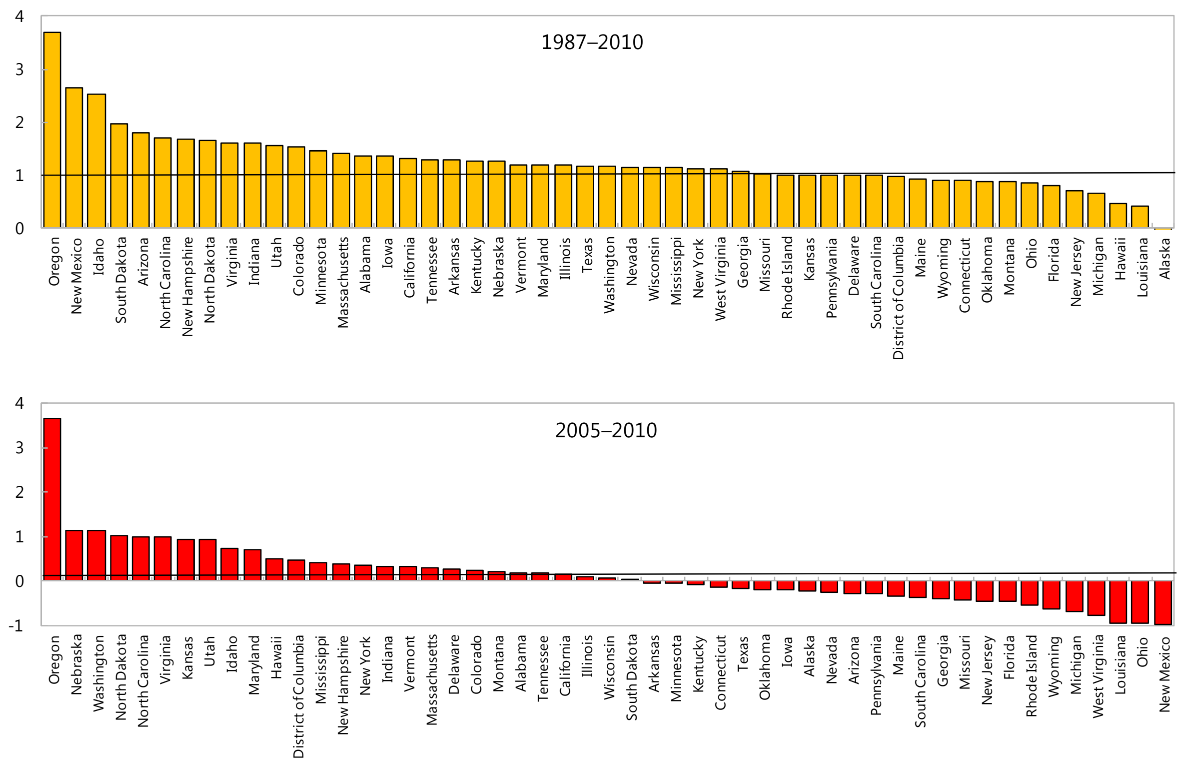
Tax structure: Own-source revenue is defined as total government revenue from own source, as a percentage of GDP, from EFNA (2013).

Government size score: The score covering three indicators (all in percent of GDP)—general consumption expenditures by government, transfers and subsidies, and social security payments—is from EFNA (2013).

Poverty rate: Percentage of state population in poverty from Sorens, Muedini, and Ruger (2008).

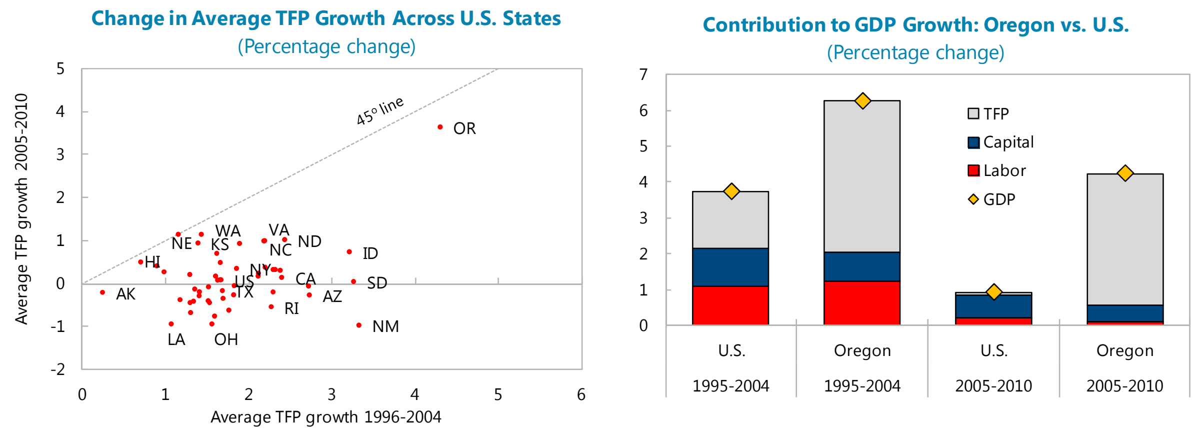
Financial sector share: Financial sector specialization is assessed as the share of "Finance and Insurance" industry (NAICS code 52) in total private industries in a given state *s* relative to the same share for the U.S. as a whole. For the construction of the synthetic index, see above.

Figure A1. Average TFP Growth Across U.S. States
(Percentage change)



Source: IMF staff estimates.

Figure A2. TFP and GDP Growth: The Case of Oregon

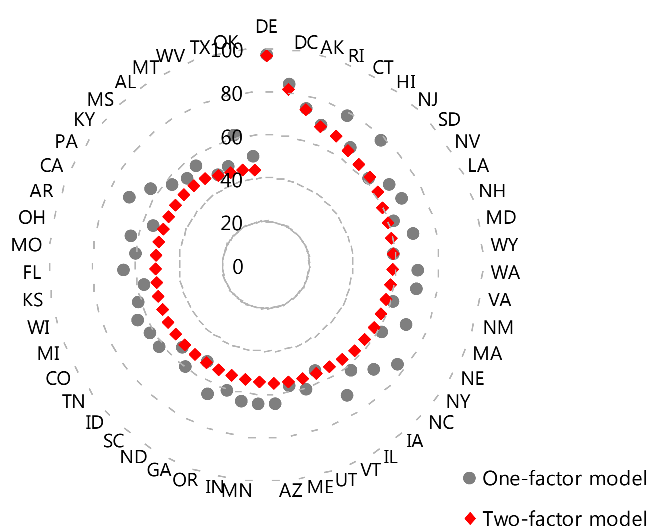


Source: IMF staff estimates.

Figure A3. Average Technical Efficiency, 1996–2010

Technical efficiency estimates derived from a time-varying inefficiency model with convergence:

- one-factor model, $\tilde{y}_{st} = \beta_0 + \beta_{K/L}\tilde{x}_{K/L,st} + \beta_t t + v_{st} - u_{st}$, with per-worker output and capital
- two-factor model, $y_{st} = \beta_0 + \beta_L x_{L,st} + \beta_K x_{K,st} + \beta_t t + v_{st} - u_{st}$



Source: IMF staff estimates.

Appendix 2. Empirical Results and Robustness Analysis

Table A1. Dummy Variable Tests of Post-2005 TFP Slowdown

(Dependent variable: log change in TFP)

$dlnTFP_{s,t} = \alpha + \beta D + \varepsilon_{s,t}$, where D={1 if year≥2005; 0 otherwise}

Tests of whether deceleration in TFP growth was stronger in IT-producing than non-IT-producing states.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-2005 dummy	-1.70***	-1.77***	-1.73***	-1.74***	-1.55***	-1.89***	-1.64***	-1.70***
	(-10.08)	(-8.17)	(-7.90)	(-7.90)	(-6.67)	(-4.12)	(-6.66)	(-4.18)
Constant	1.83***	1.84***						
	(19.56)	(18.09)						
Weighted least squares		yes	yes	yes	yes	yes	yes	yes
State fixed effects			yes	yes	yes	yes	yes	yes
Oregon excluded				yes				
Excluding IT-producing states					yes			
Only IT-producing states						yes		
Excluding ICT-producing states							yes	
Only ICT-producing states								yes
Observations	765	765	765	750	570	195	525	240
R-squared	0.13	0.16	0.38	0.37	0.31	0.46	0.30	0.45

Notes: Robust *t*-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table A2. Tests of Post-2005 TFP Slowdown for IT-Intensive States

(Dependent variable: log change in TFP)

$dlnTFP_{s,t} = \alpha + \beta D + \gamma IT_s + \delta D \cdot IT_s + \varepsilon_{s,t}$,where D={1 if year≥2005; 0 otherwise}

and IT_s is a {0,1} dummy variable or a continuous IT-intensity index

Tests of whether TFP growth in IT-intensive states has decelerated more than in non-IT-intensive states.

	(1)	(2)	(3)	(4)
Post-2005 dummy	-2.12	-1.53	-1.73***	-1.63***
	(-0.69)	(-0.50)	(-4.89)	(-4.58)
IT-intensive index	-1.48			
	(-1.06)			
Post-2005 dummy x	0.35	-0.20		
IT-intensive index	(0.11)	(-0.07)		
IT-intensive dummy			-0.30	
			(-1.47)	
Post-2005 dummy x			-0.09	-0.20
IT-intensive dummy			(-0.21)	(-0.45)
Constant	3.32**		2.00***	
	(2.33)		(11.40)	
Weighted least squares	yes	yes	yes	yes
State fixed effects		yes		yes
Observations	765	765	765	765
R-squared	0.17	0.38	0.17	0.38

Notes: Robust *t*-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Results remain robust to alternative (but potentially outdated) measures of IT-intensity summarized in Daveri and Mascotto (2006).

Table A3. Stochastic Frontier Analysis

(Dependent variable: log real GDP)

$$y_{st} = \beta_0 + \beta_L x_{L,st} + \beta_K x_{K,st} + \beta_t t + v_{st} - u_{st}$$

Time-varying inefficiency model with convergence

	1995-04	1996-05	1997-06	1998-07	1999-08	2000-09	2001-10	2002-10	2003-10	1990-10	1996-10
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Log labor	0.57***	0.60***	0.61***	0.60***	0.60***	0.61***	0.61***	0.63***	0.62***	0.62***	0.60***
	(14.42)	(14.72)	(14.98)	(14.71)	(13.97)	(13.59)	(12.52)	(12.07)	(11.17)	(21.82)	(16.11)
Log capital	0.48***	0.45***	0.45***	0.47***	0.47***	0.47***	0.47***	0.45***	0.45***	0.45***	0.49***
	(13.60)	(12.08)	(11.69)	(11.90)	(11.33)	(11.64)	(10.95)	(9.93)	(9.29)	(18.15)	(14.72)
Time trend	0.01	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.00	0.01***
	(1.55)	(3.57)	(6.51)	(6.02)	(4.27)	(2.75)	(3.74)	(3.37)	(2.70)	(0.92)	(6.97)
Constant	6.06***	6.36***	6.36***	6.20***	6.24***	6.21***	6.27***	6.49***	6.52***	6.40***	5.95***
	(12.56)	(12.92)	(12.95)	(12.21)	(12.18)	(11.95)	(11.61)	(11.49)	(10.94)	(15.00)	(13.24)
Eta	0.02***	0.01***	0.00	-0.01*	-0.01**	-0.01***	-0.01***	-0.01***	-0.01***	0.01***	-0.00
	(5.38)	(2.69)	(0.37)	(-1.65)	(-2.16)	(-3.74)	(-3.33)	(-3.86)	(-3.39)	(7.13)	(-1.41)
Observations	510	510	510	510	510	510	510	459	408	1,071	765
Number of states	51	51	51	51	51	51	51	51	51	51	51

Notes: *z*-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Eta=decay parameter (see Box 1). Regressions include time fixed effects. See Appendix 1 for the definitions and sources of variables.

Table A4. Stochastic Frontier Analysis with Conditional Inefficiency Effects

(Dependent variable: log real GDP)

$y_{st} = \beta_0 + \beta_L x_{L,st} + \beta_K x_{K,st} + \beta_t t + v_{st} - u_{st}$, with

$u_{st} = z_{st}\delta + w_{st}$ where z_{st} is a vector of explanatory variables associated with technical inefficiency of production in state *s*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Frontier							
Log labor	0.44***	0.43***	0.50***	0.43***	0.43***	0.43***	0.40***
	(23.01)	(22.74)	(19.85)	(23.04)	(21.13)	(22.07)	(22.59)
Log capital	0.60***	0.61***	0.51***	0.61***	0.60***	0.62***	0.63***
	(32.21)	(33.00)	(20.57)	(33.26)	(30.03)	(32.09)	(36.59)
Time trend	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.005***
	(6.83)	(8.74)	(3.40)	(8.98)	(8.20)	(11.11)	(4.06)
Constant	4.55***	4.42***	5.48***	4.41***	4.49***	3.99***	4.27***
	(15.08)	(12.50)	(18.48)	(17.53)	(10.85)	(18.09)	(19.83)
Mean inefficiency							
Schooling	-0.12***	-0.11***		-0.11***	-0.09***	-0.05***	
	(-15.57)	(-15.35)		(-14.43)	(-10.59)	(-3.71)	
Log schooling							-0.71***
							(-7.69)
GR dummy		0.07***	0.05***	0.08***	0.07***	0.06***	0.05***
		(5.37)	(3.02)	(5.50)	(5.45)	(3.99)	(4.09)
Tertiary educ.att.			-0.01***				
			(-12.60)				
Elementary educ.att.			-0.01***				
			(-4.47)				
Gov R&D spending				-0.02***			
				(-4.43)			
Total R&D spending					-0.02***		-0.01***
					(-5.51)		(-6.18)
Poverty rate						0.01***	
						(7.32)	
Financial sector share							-1.37***
							(-20.72)
Constant	1.97***	1.92***	0.83***	1.84***	1.57***	0.58***	2.47***
	(8.72)	(6.57)	(13.31)	(11.50)	(4.45)	(3.05)	(9.72)
Observations	1,071	1,071	561	1,071	856	900	714
Number of states	51	51	51	51	51	50	51

Notes: *z*-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1. GR dummy is the Great Recession dummy variable (=1, if year>2007; 0 otherwise). See Appendix 1 for the definitions and sources of variables.

Table A5. Determinants of Total Factor Productivity

	Fixed-Effects Estimator				Mean Group Estimator			
	Dependent variable: TFP growth				*Dependent variable: log TFP*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Schooling	0.42**							
	(2.02)							
Log schooling			5.50**	9.64***	5.00***	5.15***	4.71***	3.91***
			(1.98)	(2.69)	(4.23)	(4.02)	(4.23)	(2.94)
Tertiary educational attainment		0.16*						
		(1.70)						
Business R&D expenditure	0.36**		0.08	7.45*				
	(2.48)		(0.48)	(1.83)				
Total R&D expenditure		0.40*						
		(1.69)						
Government R&D expenditure			-0.52***	-0.48***	0.26	0.61***	0.53**	0.50**
			(-2.86)	(-2.64)	(1.15)	(2.61)	(2.55)	(2.50)
Business x Gov. R&D expenditure			0.36**	0.38**				
			(2.01)	(2.16)				
Log schooling x Business R&D exp.				-2.83*				
				(-1.81)				
Time trend					-0.02***	-0.02***	-0.02***	-0.01**
					(-3.96)	(-3.62)	(-3.77)	(-2.26)
Own-source taxes (% GDP)						2.04***	1.97***	0.77
						(3.41)	(3.35)	(1.29)
Tax burden (% GDP)						-6.38***	-6.31***	-4.46**
						(-3.11)	(-3.11)	(-2.23)
Capital expenditure (% GDP)							-0.01	
							(-0.28)	
Government size score								0.04*
								(1.65)
Constant	-4.49	-3.76	-12.75*	-23.50**	-5.68*	-5.86*	-4.65*	-3.38
	(-1.65)	(-1.39)	(-1.78)	(-2.53)	(-1.92)	(-1.83)	(-1.69)	(-0.99)
Combined effect (for interaction terms)								
Log schooling				5.68**				
				(2.05)				
Government R&D expenditure			-0.02	0.06				
			(0.08)	(0.28)				
Business R&D expenditure			0.25	0.21				
			(1.57)	(1.34)				
Time fixed effects	yes	yes	yes	yes				
State-specific time trend					yes	yes	yes	yes
Three-year averages	yes	yes	yes	yes				
Annual					yes	yes	yes	yes
Observations	346	204	346	346	1,071	950	950	950
R-squared	0.40	0.48	0.42	0.42				
Number of states	51	51	51	51	51	50	50	50

Notes: *t*-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1. See Appendix 1 for the definitions and sources of variables.

References

Baily, M.N., Manyika, J., and S. Gupta, 2013, U.S. Productivity Growth: An Optimistic Perspective, *International Productivity Monitor* 25, pp. 3–12.

Battese., G.E., and T.J. Coelli, 1995, A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, *Empirical Economics* 20, pp. 325–332.

Bauer, P.W., and Y. Lee, 2006, Estimating GSP and Labor Productivity by State, Federal Reserve Bank of Cleveland, Policy Discussion Paper n. 16.

Belotti, F., Silvio Daidone, S., Ilardi., G., and V. Atella, 2012, Stochastic Frontier Analysis Using Stata, *The Stata Journal* vv (ii), pp. 1–39.

Bernanke, B., 2013, Economic Prospects for the Long Run, Remarks at Bard, Massachusetts, http://www.federalreserve.gov/newsevents/speech/bernanke20130518a.pdf

Blanco, L., Prieger, J., and J. Gu, 2013, The Impact of Research and Development on Economic Growth and Productivity in the US States, Pepperdine University School of Public Policy Working Paper 11-1-2013.

Byrne, D.M., Oliner, S.D., and D.E. Sichel, 2013, Is the Information Technology Revolution Over? *International Productivity Monitor* 25, pp. 20–36.

Caliendo, L., Parro, F., Rossi-Hansberg, E., and P.-D. Sarte, 2014, The Impact of Regional and Sectoral Productivity Changes on the U.S. Economy, https://www.princeton.edu/~erossi/RSSUS.pdf

Council of Economic Advisors (CEA), 2014, The Annual Report of the Council of Economic Advisers, http://www.whitehouse.gov/sites/default/files/docs/full_2014_economic_report_of_the_president.pdf

Daveri, F., and A. Mascotto, 2006, The IT Revolution Across the U.S. States, *Review of Income and Wealth* 52(4), pp. 569–602.

Economic Freedom of North America (EFNA), 2013, Database, Fraser Institute, http://www.freetheworld.com/efna.html

Garofalo, G.A., and S. Yamarik, 2002, Regional Convergence: Evidence from a New State-by-State Capital Stock Series, *The Review of Economics and Statistics* 84(2), pp. 316–323.

Gomme, P., and P. Rupert, 2004, Measuring Labor's Share of Income. Federal Reserve Bank of Cleveland Policy Discussion Papers, No. 7.

Gordon, R., 2012, Is U.S. Economic Growth Over? Faltering Innovations Confronts the Six Headwinds, NBER Working Paper 18315.

Gordon, R., 2013, U.S. Productivity Growth: The Slowdown Has Returned After a Temporary Revival, *International Productivity Monitor* 25, pp. 13–19.

Fernald, J., 2014, Productivity and Potential Output Before, During, and After the Great Recession, NBER 29th Annual Conference on Macroeconomics, http://conference.nber.org/confer/2014/Macro14/macro14prg.html

Haltiwanger, J., 2011, Job Creation and Firm Dynamics in the U.S., in "Innovation Policy and the Economy," J. Lerner and S. Stern (eds), Volume 12, University of Chicago Press, pp. 17–38.

Haltiwanger, J., Hathaway, I., and J. Miranda, 2014, Declining Business Dynamism in the U.S. High-Technology Sector, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2397310

Hauk, W.R., and R., Wacziarg, 2009, A Monte Carlo Study of Growth Regressions, *Journal of Economic Growth* 14, pp. 103–147.

Hyatt, H.R., and J. R. Spletzer, 2013, The Recent Decline in Employment Dynamics, Center for Economic Studies Working Paper Series 13-03, U.S. Census Bureau, March, http://www2.census.gov/ces/wp/2013/CES-WP-13-03.pdf

Isaksson, A., 2007, Determinants of Total Factor Productivity: A Literature Review, Research and Statistics Branch Staff Working Paper 02/2007, United Nations Industrial Development Organization.

Jerzmanowski, M., 2007, Total Factor Productivity Differences: Appropriate Technology vs. Efficiency, *European Economic Review* 51, pp. 2080–2110.

Jorgenson, D.W., Ho, M., and J. Samuels, 2010, Information Technology and U.S. Productivity Growth: Evidence from a Prototype Industry Production Account, prepared for M. Mas and R. Stehrer (eds) "Industrial Productivity in Europe: Growth and Crisis."

Kumbakhar, S.C., and C.A.K. Lovell, 2000, Stochastic Frontier Analysis, Cambridge University Press, Cambridge, U.K.

LaSage, J., and R.K. Pace, 2009, Introduction to Spacial Econometrics, Statistics: Textbooks and Monographs, CRC Press, Taylor & Francis Group.

Lee, G., and J. Perry, 2002, Are Computers Boosting Productivity? A Test of the Paradox in State Governments, *Journal of Public Administration Research and Theory* 12(1), pp. 77–102.

Panda, B., 2010, Productivity Growth of the US States, A Dissertation, Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College, http://etd.lsu.edu/docs/available/etd-11112010-204900/unrestricted/Panda_Dissertation.pdf

Sharma, S.C., Sylwester, K., and H. Margono, 2007, Decomposition of Total Factor Productivity Growth in U.S. States, *The Quarterly Review of Economics and Finance* 47, pp. 215–241.

Sorens, J., Muedini, F., and W. Ruger, 2008, State and Local Public Policies in 2006: A New Database, *State Politics and Policy Quarterly* 8(3), pp. 309–326.

Stiroh, K.J., 2002, Information Technology and the U.S. Productivity Revival: what Do the Industry Data Say? *The American Economic Review* 92(5), pp. 1559–1576.

Syverson, Ch., 2011, What Determines Productivity, *Journal of Economic Literature* 49(2), pp. 326–365.

Tarullo, D., 2014, Longer-Term Challenges for the American Economy, Remarks at "Stabilizing Financial Systems for Growth and Full Employment" 3rd Annual Hyman P. Minsky Conference on the State of the U.S. and World Economies, http://www.federalreserve.gov/newsevents/speech/tarullo20140409a.pdf

Turner, Ch., Tamura, R., Mulholland, S. E., and S. Baier, 2006, Education and Income of the States of the United States: 1840–2000, *Journal of Economic Growth* 12, pp. 101–158.

Turner, Ch., Tamura, R., and S. E. Mulholland, 2013, How Important are Human Capital, Physical Capital and Total Factor Productivity for Determining State Economic Growth in the United States, 1840–2000? *Journal of Economic Growth* 18, pp. 319–371.

Yamarik, S., 2013, State-Level Capital and Investment: Updates and Implications, *Contemporary Economic Policy* 31(1), pp. 62–72.