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Digitization and Productivity: Measuring Cycles of Technological Progress

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Shushanik Papanyan

Abstract

This paper investigates the dynamics of technological progress as the underlying trend in productivity growth. We employ a multi-factor approach to measuring the long-term productivity trend, where this trend encompasses everything that permanently raises output per hour. The paper also employs an alternative measure of technological progress, measuring the trend and cycle components in information technology (IT) expenditures. For both measures, we model the technology trend as a process whose mean growth rate has two independent regimes. We find that technological progress estimated as the long-term productivity trend is in a low-growth regime, while the IT expenditures trend is in a high-growth regime and serves to boost the productivity growth rate. We also find that IT expenditures have wider cyclical swings than those of U.S. business cycles. At the same time, the switch in the IT trend from the high-growth to low-growth state does not coincide with the dates of U.S. recessions and exhibits several more high-growth episodes than does the productivity trend. Additionally, we estimate all the models in per-labor-hour and per-capita terms and find that per-capita estimates begin to diverge visibly from per-labor-hour estimates starting in the mid-1980s.

Keywords: Productivity growth; Neoclassical growth model; Factor model; Comovement; Nonlinear; Markov switching; Regime-switching; Unobserved components

JEL: C32, E32, O3, O4, O51

1 Introduction

The U.S. productivity growth rate over the last five years from 2011 to 2015 has slowed significantly to 0.5%. Contrast this to the 3% average productivity growth rate that the U.S. saw in the historic time periods from post-WWII to 1973 and from 1996 to 2004. Economists studying productivity and innovation are divided on how electronic inventions have affected U.S. productivity, and how digital innovations will contribute to the future path of productivity growth. Prominent economist Robert Gordon is very much at odds with pro-Silicon Valley economists' views on productivity and growth. The pro-Silicon-Valley stance is that despite current stagnant productivity growth rates, a steep pick-up in productivity is on the horizon. The co-founder of MIT's Initiative on the Digital Economy, Erik Brynjolfsson assesses that the electronic age and the internet have created an abundance of innovation that can reach the globe through already established internet networks and that can be digitalized and copied at near zero cost. The pro-Silicon-Valley economists also argue that while we live in the economics of abundance, we refuse to pay for the digitalized services and products, thereby creating a measurement problem for GDP and productivity growth.[1] On the other hand, Gordon has a contrary assessment of the future of the U.S. He is certain that the past discoveries of electricity, heating, and the internal combustion engine have been "infinitely more important for boosting productivity and enhancing living standards than anything produced by the dot.com boom" and the new digital era. Most importantly, he predicts that the contributions to productivity from the technological advancements of the last few decades and from those expected in the near term future will be reduced because of existing structural headwinds, such as demographics, education, debt, and inequality.[2]

Our estimations show that the recent slowdown in U.S. productivity growth rates has been structural in nature and will persist beyond the current cyclical decline and post-great recession recovery. First, we measure technological progress as the underlying trend in productivity growth. We employ a multi-factor approach to measuring the long-term productivity trend, where this trend encompasses everything that permanently raises output per hour – total factor productivity (TFP), capital deepening, and growth in human capital. This modeling approach has its roots in neoclassical growth theory with the implication that labor productivity, labor compensation, consumption, and investment share a common trend. Additionally, we model the productivity trend as a process whose mean growth rate has two regimes with a probability of switching between the two at any point in time, which allows for identifying low-growth and high-growth regimes for the trend. The original estimation of the regime-switching model for productivity (Kahn and Rich, 2007) excluded investment. To understand the contribution of technology to productivity growth, several additional models were estimated beyond the benchmark model, which was estimated with labor productivity, labor compensation, and consumption. The additional models are as follows: a) consumption (C) was replaced with investment (I), b) consumption was replaced with investment expenditures on information processing equipment, software and research and development (IT), c) investment was added to the benchmark (named C&I), and d) where information technology was added to the benchmark (named C&IT).

[1] Erik Brynjolfsson is Schussel Family Professor of Management Science at the MIT Sloan School of Management and Co-Founder of MIT's Initiative on the Digital Economy. Erik Brynjolfsson's TED "The Key to Growth? Race with the Machines" (February, 2013) https://goo.gl/GIMefy

[2] Robert J. Gordon is the Stanley G. Harris Professor of the Social Sciences at Northwestern University. He has written extensively about the problems of economic growth. He has authored hundreds of scholarly including: "Is US Economic Growth over? Faltering Innovation Confronts the Six Headwinds," (NBER Working Paper No. 18315; 2012) and "Why Innovation Won't Save Us" (Wall Street Journal, December 21, 2012). Robert Gordon TED "The Death of Innovation, the End of Growth" (February, 2013) https://goo.gl/joNX6j

Secondly, we propose a different measure of technological progress, measuring the trend in IT expenditures. The IT expenditures component of U.S. investments also has a dominant cyclical component. We employ univariate trend-cycle decomposition, where the trend is modeled as a stochastic process that undergoes upswings and downswings with switches from a high-growth regime to a low-growth regime.

Our estimations show that technological progress estimated as the long-term productivity trend is in a low-growth regime, while the IT expenditures trend is in a high-growth regime and serves to boost the productivity growth rate. We find that while domestic investment is an important part of measuring productivity and technological progress, the models containing investment expenditures have a lower productivity trend, while models containing IT expenditures have a higher productivity trend. We also find that while always dropping during recessionary periods, IT expenditures have wider swings when compared to U.S. business cycles. At the same time, the switch in the IT trend from the high-growth to low-growth state does not coincide with the dates of U.S. recessions and exhibits several more high-growth episodes than does the productivity trend. Additionally, we estimate all the models in per-labor-hour and per-capita terms and find that per-capita estimates begin to diverge visibly from per-labor-hour estimates starting in the mid-1980s.

The paper is organized as follows. The second section describes the data, econometric model, and estimation results for the multivariate productivity trend estimations. The third section provides the model, data, and estimation results for the univariate measure of technology. Section four concludes the paper.

2 Definition of Technological Progress

Technological progress forms the underlying trend in productivity growth, while sustained productivity growth is the primary source of growth in long-term living standards. However, aggregate measure of productivity, measured as labor productivity is volatile and dominated by transitory, cyclical fluctuations. Stripping out the strong cyclical component of productivity growth and understanding the long-term trend in productivity growth is essential. Assessment and timely measurement of the productivity trend is crucial for policy makers in evaluating correctly recessionary or inflationary output gaps and in conducting growth-promoting policies.

We employ a multifactor approach to measuring productivity which yields a reliable and more suitable estimate of the long-term productivity trend, where the productivity trend measure of technology encompasses everything that permanently raises output per hour – total factor productivity (TFP), capital deepening, and growth in human capital. The neoclassical growth theory model that provides the backdrop for this empirical estimation is detailed in Kahn and Rich (2007). The neoclassical model implications are that labor productivity, labor compensation, consumption, and investment share a common trend. The trend measures the level of technological progress. Additionally, modeling the productivity trend as a process whose mean growth rate has two regimes, with a probability of switching between the two at any point in time, allows differentiating low-growth and high-growth regimes for the trend.

This modeling approach relies on theory to confine the analysis to a low dimensional system of variables and that therefore differs from non-theoretical applications of factor models that involve a large number of variables or that do not place theory-based restrictions on estimated coefficients[3] (Kahn and Rich, 2007). The estimations approach draws on the regime-switching multivariate dynamic factor model proposed by Kim and Murray (2002) and Kim and Piger (2002), and utilizes the comovement among macroeconomic variables to identify a shared factor – a common permanent component. Additionally, the regime-switching specification allows the permanent component to account for persistent changes in trend growth without making the growth process itself nonstationary.

The original estimation of similar regime-switch model for productivity (Kahn and Rich, 2007), however, excluded investment. Yet gross domestic investment is an important part of measuring productivity and technological progress. To understand the contribution of technology to productivity growth, several additional models were estimated beyond the benchmark model, which is estimated with labor productivity, labor compensation, and consumption. These additional models utilize estimation of productivity growth where a) consumption (C) is replaced with investment (I), b) consumption is replaced with investment expenditures on information processing equipment, software and research and development (IT), c) investment is added to the benchmark (named C&I), and d) where information technology is added to the benchmark (named C&IT).

2.1 Model Specification: Unobserved Components Model

The model presented in this section is a nonlinear multivariate unobserved components model that can serve as a generalized multivariate framework to measure the significance of common permanent and transitory components in business cycle fluctuations. This framework is suitable. It comprises two important features in measuring business cycles: a) the decomposition of integrated series into stochastic trend and cyclical

[3] See for example, Stock and Watson (1989, 2002)

components emphasized in Carvalho and Harvey (2003), Luginbuhl and Koopman (2003), and b) a dynamic factor model that is important for the isolation of common components from idiosyncratic components, which was the primary focus in Stock and Watson (1989, 1991, and 1993). To account for the asymmetric behavior of the trend, the unobserved components model presented below also incorporates regime switching between the expansionary and recessionary phases of the business cycle for the common permanent component. Morley and Piger (2005) find that Markov regime switching models outperform linear models at reproducing the variability of growth rates in different phases of business cycles. The unobserved components model is characterized by the following equations:

$$Y_{it} = \gamma_i T_t^c + \alpha_i c_t^c + \tau_{it} + c_{it} \tag{1}$$

$$\phi^{\tau}(L)\Delta T_t^c = \mu_{St}^c + \upsilon_t,\ \upsilon_t \sim iidN(0,\sigma_{\upsilon}^2) \tag{2}$$

$$\phi^{c}(L)c_t^c = u_t,\ \ u_t \sim iidN(0,\sigma_u^2) \tag{3}$$

$$\tau_{it} = \mu_i + \tau_{it-1} + \omega_{it},\ \omega_{it} \sim iidN(0,\sigma_{\omega_i}^2) \tag{4}$$

$$\psi_i(L)c_{it} = \varepsilon_{it},\ \varepsilon_{it} \sim iidN(0,\sigma_{\varepsilon_i}^2) \tag{5}$$

where Y_{it} is 100 times the log of the individual time series, i = 1, ..., N, and N is the number of time series. The model can be easily extended to include more series. Y_{it} is decomposed into T_t^c, the common stochastic trend, τ_{it}, the idiosyncratic stochastic trend, c_t^c, the common cyclical component, and c_{it}, the idiosyncratic cyclical component. Both the common cycle and the idiosyncratic cycle are assumed to follow an autoregressive process. γ_i and α_i are factor loadings for the common trend and the common cycle respectively. γ_i indicates the extent to which each series is affected by the common permanent component, while α_i indicates the extent to which each series is affected by the common transitory component. For identification of the model, the variances of common components are normalized to one. The model is estimated in differences and is written in deviations from means. Due to our interest in the common permanent component, we estimate a trend only model as

$$\Delta y_{it} = \gamma_i \Delta\tau_t^c + z_{it} \tag{6}$$

where $\Delta y_{it}, \Delta\tau_t^c, z_{it}$ are defined as $\Delta y_{it} = \Delta Y_{it} - \Delta\overline{Y}_i$, $\Delta\tau_t^c = \Delta T_t^c - \delta$, $z_{it} = \alpha_i \Delta c_t^c + \Delta c_{it} + \Delta\tau_{it}$. We allow $\Delta\tau_t^c$ and z_{it} to follow the processes described in equations (7) and (8) respectively. The common permanent component is subject to Hamilton (1989) regime switching.

$$\phi^{\tau}(L)\Delta\tau_t^c = \mu_{St} + \upsilon_t,\ \upsilon_t \sim N(0,1) \tag{7}$$

$$\mu_{St} = \mu_0(1-S_t) + \mu_1 S_t$$

$\mu_{S_{1t}}$ is defined as $\mu_{St} = \mu^c - \delta$, and S_t is a Markov switching state variable that switches between 0 and 1 and that has q and p transition probabilities such that:

$$S_t = \{0,1\},\ \Pr[S_t = 0|S_{t-1} = 0] = q,\ \Pr[S_t = 1|S_{t-1} = 1] = p$$

The remaining component z_{it} follow an autoregressive process such as:

$$\psi_i(L)z_{it} = \eta_{it},\ \eta_{it} \sim iidN(0,\sigma_i^2) \tag{8}$$

To estimate the parameters, as well as the unobserved components of the model, the state space representation of the model is used to apply Kalman filtering and Kim's (1994) approximate maximum likelihood estimation algorithm. The model is estimated in GAUSS.

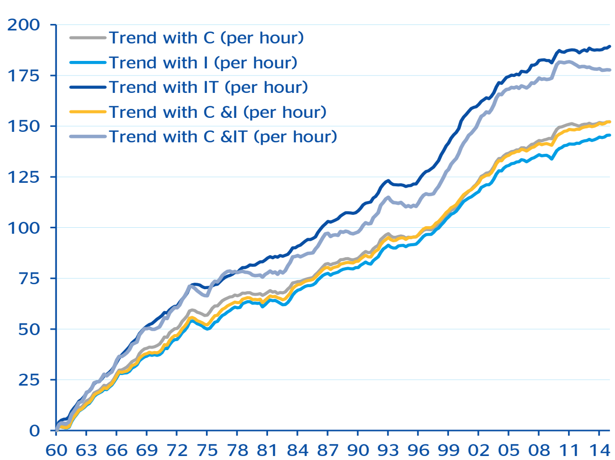
2.2 Data

The model presented in section 2.1 is estimated for the log of quarterly nonfarm business real output per hour of all persons, nonfarm business sector compensation per hour of all persons, real personal consumption expenditures per hour of all persons, real private fixed investment per hour of all persons, and real private nonresidential fixed investment on information processing equipment, software and research and development per hour of all persons. The model is also estimated in per capita terms. The nonfarm business sector real output, real compensation and hours of all persons data is reported by Bureau of Labor Statistic. The real personal consumption expenditures, real private fixed investment, and real private nonresidential fixed investment on information processing equipment, software and research and development data is reported by Bureau of Economic Analysis. The resident population is reported by the U.S. Census Bureau. The time series are seasonally adjusted by the original sources of the data.

2.3 Empirical Results

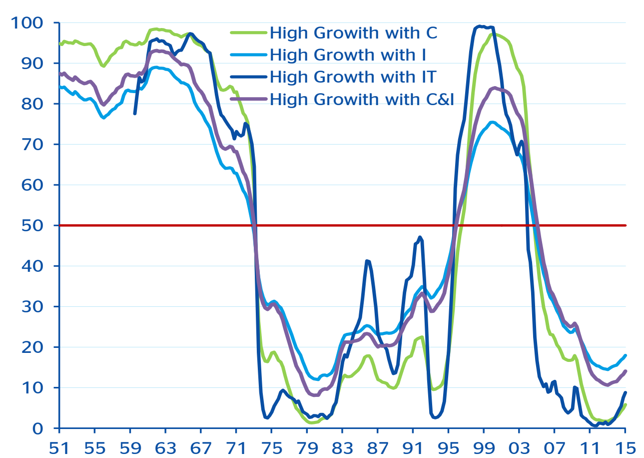
Our estimations show that the models containing investment expenditures have a lower productivity trend, while models containing IT expenditures have a higher productivity trend (Chart 1). Notably, our estimations show that the recent slowdown in U.S. productivity growth rates has been structural in nature and will persist beyond the current cyclical decline and post-great recession recovery. As depicted in Chart 2, long-term productivity has been in a low-growth regime since 2004. The U.S. post World War II growth rates of productivity mark four distinct time-periods that alternated between high-growth and low-growth rates. The first high-growth period ended in 1973, coinciding with the oil crisis-recession. Yet while the rest of the developed nations remained in the low growth state, the U.S. economy shifted to higher growth levels in 1996. However, this high growth period lasted for only 8 years, shifting back to low-growth in 2004.

Chart 1
Multifactor Productivity Trend
(Per Labor Hour, Logarithmic Scale, 4Q59=0)



Source: BBVA Research

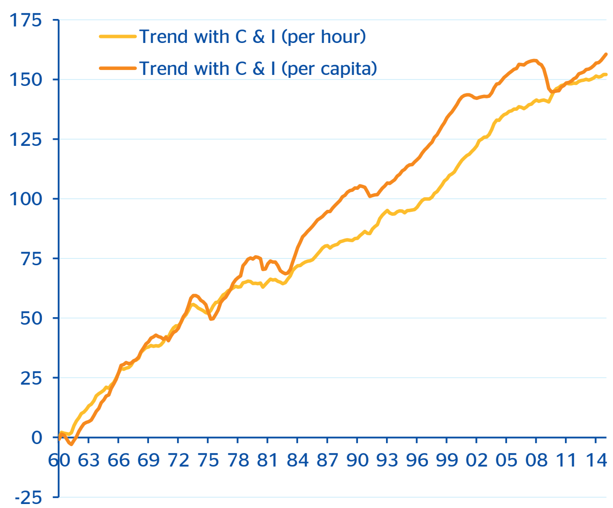
Chart 2
Probability of High Growth State of Productivity Trend
(Per Labor Hour, %)



Source: BBVA Research

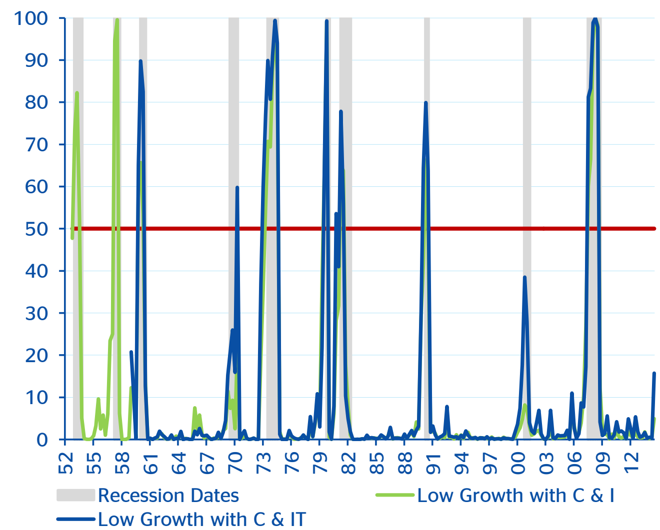
Estimations of per capita multifactor technology trend component also employ that models containing investment expenditures have a lower productivity trend while models containing IT expenditures have a higher productivity trend. However, per-capita technology trend yields different outcomes with regard to mean growth probability switch from high-growth regime to low-growth regime. It is highly pro-cyclical and switches to a low-growth regime during six out of ten U.S. recessions that the time series are available for. Additionally, we find that the dynamics of technology trends in the per-capita estimates begin to diverge visibly from per-labor-hour estimates starting in the mid-1980s (Chart 3).

Chart 3
Multifactor Productivity Trend (Logarithmic Scale, 4Q59=0)



Source: BBVA Research

Chart 4
Probability of Low Growth State of Productivity Trend (Per Capita, %)



Source: BBVA Research

3 Measuring Technology with Information Technology Expenditures

Similar to productivity itself, the IT expenditures component of U.S. investments also has a dominant cyclical component. We propose another measure of technological progress that encompasses the trend of IT expenditures, where IT expenditures are decomposed into permanent and cyclical components.

3.1 Model Specification and Data

In line with Hamilton (1989), the mean of growth in IT expenditures is modeled to evolve according to a two state Markov-switching process, while growth is modeled as an autoregressive process

$$y_t = \tau_t + c_t \quad (1)$$

$$\tau_t = \mu_{St} + \tau_{t-1} + \omega_t,\ \omega_t \sim iidN(0, \sigma_\omega^2) \quad (2)$$

$$\psi(L)c_t = \varepsilon_t,\ \varepsilon_t \sim iidN(0, \sigma_\varepsilon^2) \quad (3)$$

where y_t is 100 times the log of the time series and is decomposed into τ_t stochastic trend, and c_t, the cyclical component, and c_{it}, the idiosyncratic cyclical component modeled as an autoregressive process. $\mu_{S_{1t}}$ and S_t are Markov switching state variables, where S_t switches between 0 and 1 and have q and p transition probabilities such that:

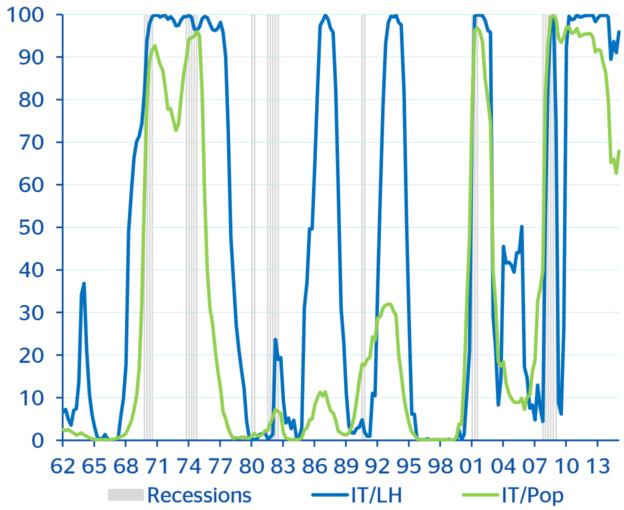
$$\mu_{St} = \mu_0(1 - S_t) + \mu_1 S_t$$
$$S_t = \{0,1\},\ \Pr[S_t = 0 | S_{t-1} = 0] = q,\ \Pr[S_t = 1 | S_{t-1} = 1] = p$$

The model is estimated for the log of quarterly real private nonresidential fixed investment on information processing equipment, software and research and development in both per-hour-of-all-persons terms and in per-capita terms.

3.2 Empirical Results

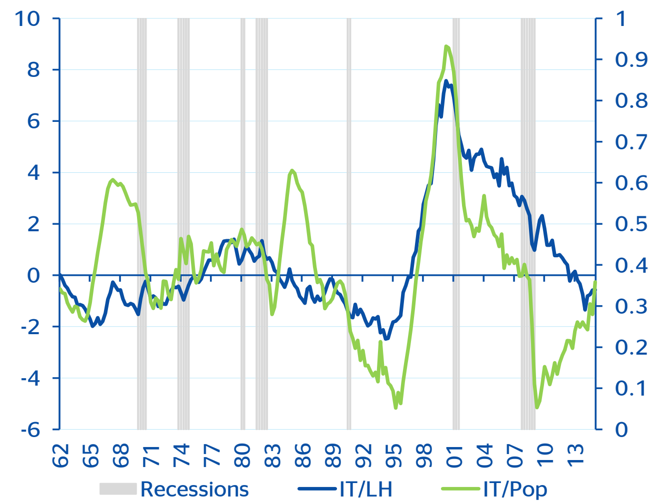
A univariate decomposition of IT expenditures to the cyclical component and long-term trend reveals quite a different outcome than the multivariate technological progress trend results. Both per hours and per capita measures of IT expenditures yield similar results when decomposed to trend and cycle components. While always dropping during the recessionary periods, IT transitory components has larger swings in comparison to U.S. business cycles. At the same time, the switch in the IT trend from the high-growth to low-growth state does not coincide with the dates of U.S. recessions and exhibits several more high-growth episodes than does the productivity trend. Both per capita and per labor measures of IT trend are currently in a high-growth state.

Chart 5
Probability of High-Growth State of IT Trend (%)



Source: BBVA Research

Chart 6
Cyclical Component of IT (%)



Source: BBVA Research

4 Conclusions

Our estimations confirm that the post-great recession slowdown in U.S. productivity growth rates has been structural. We find that technological progress measured as the trend in productivity growth is in a low-growth state, while technology, measured as the trend in IT, is in a high-growth state and boosts the productivity growth rate. We also conclude that domestic investment is an important part of measuring productivity and technological progress. Furthermore, the models containing investment expenditures have a lower productivity trend, while models containing IT expenditures have a higher productivity trend. We also find that while always dropping during recessionary periods, IT expenditures have wider swings when compared to U.S. business cycles. At the same time, the switch in the IT trend from the high-growth to low-growth state does not coincide with the dates of U.S. recessions and exhibits several more high-growth episodes than does the productivity trend. Furthermore, we estimate all the models in per-labor-hour and per-capita terms and find that per-capita estimates begin to diverge visibly from per-labor-hour estimates starting in the mid-1980s.

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