Aggregate Fluctuations and ICT[*]

Very preliminary and incomplete

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May 14, 2011

Abstract. This paper investigates the role of different sources of technological progress as determinants of long run and short run U.S. postwar produtivity. We break out technological progress into neutral and investment-specific technical change, and this last is itself split into ICT and non-ICT technical change. The paper points out three main results. First, the three sources of technological progress are mutually interrelated and their dynamics have changed sensibly over the last 50 years. Second, the contribution of investment-specific progress (both ICT and non-ICT) to both growth and cyclical flutuations of productivity has increased over time, while the importance of neutral technological progress has diminished. Interestingly, technology embeded in not-ICT assets has gained a leading role over the years in accounting for these fluctuations, contrarily to conventional widsdom which associate this role to the ICT assets. Finally, we find evidence that the entire reduction in the volatility of productivity observed during the moderation of some variances (that of GDP and hours) can be associated with a reduction of the variances of the neutral progress and the ICT investment specific tecnnical change, while that of the non-ICT variance remained stable during the sample. This last finding implies that nowadays the shocks to non-ICT sector play a crucial role in determining variations of U.S. productivity.

JEL classification: E32, O47

Keywords: Productivity growth; ICT; Investment-specific technological change; Neutral technological change

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[*] Comments and suggestions from Víctor Ríos Rull, Fabio Canova, Claudio Michelacci, and participants at the Workshop on Dynamic Macroeconomics (Punta Umbría 2009) are gratefully acknowledged. We wish to thank Raúl Santaeulalia for the help in managing the dataset. Financial support from Junta de Andalucía P07-SEJ-02479 and from Ministerio de Educación SEJ2006-04803/ECON are acknowledged. Contacting author: Jesús Rodríguez López, `jrodlop@upo.es`

1 Introduction

The economic literature has widely documented three important facts regarding U.S. macroeconomic productivity during the past four decades. First, the productivity slowdown of 1974 (see Greenwood and Yorukoglu (1997), among others) followed by a considerable decline in the growth rates of output as compared to previous years. Second, the productivity upsurge of 1995 and onward, when both GDP and productivity showed high growth rates. This increase in productivity has been associated with the rise of information and communication technologies [henceforth, ICT], as pointed out in Collechia and Schreyer (2001), Stiroh (2002), Jorgenson (2002). While the first episode was not exclusive to the U.S. economy (all other OECD economies also suffered a contraction in growth rates), the second episode has been more prominent in the U.S. than in other economies. For this reason, we use U.S. econoomy as preferred lab to assess the contribution of ICT to productivity. Third, the volatility of productivity and its components, i.e. output and labor, evinced a drastic reduction beginning in the first quarter of 1984. This evidence belong to the generalized reduction in variance of macroeconomic aggregates called the "Great Moderation" (McConnell and Pérez-Quirós, 2000; Stock and Watson, 2000). EU countries and the Japanese economy also experienced the Moderation, even though of a smaller magnitude (Stock and Watson, 2005).

The goal of present paper is to analyze the role of different sources of technological progress in shaping the dynamics of productivity and its upward and downward jumps during the postwar sample. In particular, we ask to which extension the observed variations in productivity can be explained by changes in the dynamics of the different technological processes, or by changes in their relative importance as determinants of productivity. As a matter of fact, the paper shows that technological progress exhibits very different patterns within the postwar period when analyzed in different subsamples, or when separated according to the origin of the innovation. Besides, we test whether the relative importance of ICT as determinant of productivity changed when switching from the 60's to the 90's. This analysis is intended to shed light on the debated issue that the adoption of ICT capital might be the responsible for the reduction of volatility in the series of productivity and prices, due to the increased ability of firms to gather and process information for arbitraging against future occurrences.[1]

We adopt the view that technological progress can be caused by three complementary sources: neutral technological change, investment-specific technological change to ICT assets, and investment-specific technological change to non-ICT assets. While the former is associated with multifactor productivity, the latter two refer to changes in the quality of investment goods. The distinction between non-ICT and ICT equipment is justified by the fact that investment specific technology can widely vary from one asset to another.[2] In order to construct a proxy for investment-specific technological change [henceforth, ISTC], we use the series of quality adjusted prices of investment estimated by Gordon (1990) and later extended by Cummins and Violante (2002). We find the following evidence about the processes of technology. First, ISTC progress has shown a substantial acceleration since 1974(see Greenwood and Yorukoglu, 1997; or Fisher, 2006), while neutral progress has the opposite pattern. We depart from this literature by further investigating whether the sector that triggered the increase in productivity was

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[1] Put references.

[2] Put references.

actually ICT. Second, the series of neutral and ISTC in ICT have become much less volatile since 1984, while the variance of ISTC in non-ICT remained stable over the considered sample. Finally, we find that the dynamics of the three processes are mutually interrelated with spillovers that change substancially from the first to the last part of the sample.

In order to investigate the effects of previous changes in the dynamics of technology on productivity and its components, i.e. output and labor, we use a DSGE model with several capital assets that we calibrate to match some long run facts about the postwar U.S. economy. Our main findings are as follows. First, long run growth has been led by ISTC, whose importance has increased over time. Second, before 1974 most output deviations from the balanced growth path were caused by shocks to the neutral progress. Third, the role of shocks to ISTC increased substantially after 1984, more than doubling their weights as sources of fluctuations of productivity and its components. Neutral progress, however, is still the main determinant of productivity fluctuations, although its relative weight substantially decreased, from 91% to 51%. Fourth, the observed volatility reduction of the technology shocks suffices to generate a reduction of the same magnitude in the simulated volatility (for productivity, GDP and hours). While related literature associates the moderation with improvements in financial markets, good monetary policy practices, we argue that such a moderation is a technological issue. Yet, the simulated moderation of variables in our model is due to the switching stochastic representations of technological processes, as estimated from the data. Thus, our finding also bring evidence in support of the "good luck" view of the Great Moderation.[3]

Another interesting finding of this paper is to show the nature of the spillovers among the three sources of technological change. In this respect, our analysis suggests that neutral shocks and ISTC shocks should be identified jointly and not separately, and that they both contributes to the dynamics of TFP.

1.1 Related literature

A number of studies relate to this paper. Greenwood, Hercowitz and Krusell (1997, 2000) decomposed the long run growth of output per hour worked using a series of hedonic prices for capital estimated by Gordon (1990) and found that investment-specific progress accounts for 58% of total growth across 1954-1990. They also used a calibrated model for the same period and found that 30% of output fluctuations are caused by the shock to investment-specific progress. These results were later extended and confirmed by Cummins and Violante (2002). Within a similar framework, Pakko (2002) analyzed the transition dynamics due to changes in the growth rates of neutral and investment-specific technologies. The paper aimed to explain how changes in first order moments of technological progress may affect the long run adjustment of capital stock. Such changes induce firms to alter the optimal combination of capital and labor, resulting in a longer period during which observed productivity lags behind technology patterns. This explains the so called productivity paradox during the new economy age.

Regarding the literature on the second order moments of the macroeconomic time series, Arias, Hansen and Ohanian (2006) performed a calibration exercise that analyzes the moderation in volatilities around 1984 using a variety of shocks: a TFP shock, a government spending shock, a shock affecting

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[3] Put references.

the substitution between consumption and labor, and a shock to the inter-temporal Euler equation. They estimate that the variances of these shocks were reduced after the first quarter of 1984 and show that a TFP shock (or a neutral technology shock) can respond substantially to the observed volatility declines in output and other macroeconomic variables. Note that this analysis only considers one form of technological progress, i.e., neutral progress, therefore neglecting the investment-specific channel.

A few recent econometric papers – Fisher (2006) and Justiniano and Primiceri (2008) – tackled the issue the Great Moderation. According to the model of Greenwood et al. (1997, 2000), Fisher (2006) proposed a set of identifying conditions for the two technology shocks. In the long run, the relative price of investments is assumed to be affected solely by the investment-specific shock, while the growth rate of productivity is assumed to be affected by both types of shocks. The sample is divided into two subperiods, 1955.1-1979.2 and 1982.3-2000.4, where investment-specific shock is found to play a crucial role in accounting for hours and output fluctuations. Justiniano and Primiceri (2008) estimated a DSGE model to analyze the different sources of U.S. fluctuations, which include shocks to technology (divided into neutral and investment-specific), shocks to preferences, fiscal shocks and nominal shocks. Differently to us, they did not use quality adjusted investment prices to proxy for investment-specific technological change, estimated the model considering shocks to technology unobservable. They found that investment-specific technological shock can account for most US output fluctuations and most of the decline in GNP volatility after 1984. They also found that the volatility of the series identified as technology stocks fell between 1/3 and 4/5 after 1984.

The structure of the paper is as follows. Section 2 presents the data and some preliminary evidence. A DSGE model with embodied technological progress is presented in Section 3. Sections 4 and 5 study the relationships between technology and the long run and the short run, respectively. Section 6 summarizes and concludes.

2 Data and Evidence

Data on gross national product (GNP), consumption, investment and the official price index for investment in equipment come from the National Income and Product Accounts from the Bureau of Economic Analysis (NIPA-BEA)[4]. The aggregate hours index (PRS85006033) as a proxy for total hours worked[5] are from the Bureau of Economic Statistics (BLS).

Capital is disaggergated into three assets: structures, ICT equipment and non-ICT equipment. We assume that only these two lasts are affected by the investment specific technical change. Investment in ICT assets are deflated by the quarterly NIPA (quality-adjusted) price. For the non-ICT asstes, that comprise a collection of traditional equipment (machinery, transport equipment, engines, etc.), we use the annual quality adjusted price index from Cummins and Violante (2000) for investment in equipment and annual quality adjusted depreciation rates of total capital. These series, labeled as GCV prices, extend those previously calculated by Gordon (1989) to the year 2000. Following Fisher (2006) and Ríos-Rull et al. (2009), these annual series of quality adjusted prices are quarterlized using the method of Denton (1971), where quarterly fluctuations are those from the official price index for investments in

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[4] `http://www.bea.gov/index.htm`

[5] `http://www.bls.gov/`

equipment from the BEA Database (NIPA prices). This price index is used to extend the price series through 2001-2008. This allows us to analyze the period from 1948.1 to 2008.4.

Series of investments in both the ICT chapter and the non-ICT equipment chapter are aggregated using a Törnqvist index. As a deflator for the investment in structures, let us call P_t a Törnqvist price index of nondurables and services. Structures and the two types of equipment include private and government expenditures. Non-ICT equipment investment also account for inventory changes and consumer durables expenditures. This provides us with three price index, $q_{ict,t}$, $q_{nict,t}$, and P_t. The investment-specific technological progress (henceforth ISTC) in capital $j = ict$, $nict$ is calculated as

$$Q_{j,t} = \frac{P_t}{q_{j,t}}, \tag{1}$$

which represents the amount of capital $j = ict$, $nict$ that can be purchased by one unit of output at time t. Note also that for structures no ISTC is allowed for, $Q_{str,t} = 1$.

For $j = ict$,$nict$, we next assume that these ISTC is governed by a linear trend, η_j, and hit by a technology shock, $\varepsilon_{j,t}$, in every single period,

$$Q_{j,t} = Q_{j,0} \left(1 + \eta_j\right)^t \phi\left(B\right) \varepsilon_{j,t},$$

where

$$\left(\begin{array}{c} \varepsilon_{ict,t} \\ \varepsilon_{nict,t} \end{array} \right) \sim \mathcal{N} \left[\left(\begin{array}{c} 0 \\ 0 \end{array} \right), \left(\begin{array}{cc} \sigma^2_{ict} & 0 \\ 0 & \sigma^2_{nict} \end{array} \right) \right].$$

Using a series of investment in terms of the consumption good (nondurable and service), the stock of capital $j = ict$,$nict$ is constructed from the law of motion,

$$K_{j,t+1} = \left(1 - \delta_j\right) K_{j,t} + Q_{j,t} I_{j,t}, \tag{2}$$

where δ_j is the Cummins-Violante's physical (quality adjusted) depreciation rate[6]. Investment $I_{j,t}$ is expressed in terms of the consumption good, while product $Q_{j,t}I_{j,t}$ expresses investment in efficiency units. Hence, total nominal investment (including both structure and equipment expenditures) is deflated using the Törnqvist price index of nondurables and services, P_t. The nominal GNP is also deflated using this index, P_t. Y_t is defined as the GNP in terms of the consumption good.

Finally, neutral technological change A_t can computed residually from a constant return to scale Cobb-Douglas technology,

$$\begin{aligned} Y_t &= A_t L_t^{\alpha} K_{str,t}^{\alpha_{str}} K_{nict,t}^{\alpha_{nict}} K_{ict,t}^{\alpha_{ict}}, && (3) \\ \alpha_{str} + \alpha_{ict} + \alpha_{nict} &= 1 - \alpha, && (4) \end{aligned}$$

where L_t is total hours worked, measured by the aggregate index of hours from the BLS.

Let us first look at expressions (2) and (3) to understand how shocks to the ISTC, $Q_{j,t}$, can be transported to the neutral progress, A_t. Assume that $Q_{j,t}$ is boosted by a positive shock $\varepsilon_{j,t}$. As capital

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[6] For the sake of simplicity, the rate of depreciation is written as a parameter, i.e. without a time subscript, although the rate provided by Cummins and Violante is an annual serie.

is measured in efficiency units, $Q_{j,t}I_{j,t}$, the accumulated stock of this asset increases by (2). Provided that A_t is residually estimated, it must also reflect the evolution of such a shock. Yet it happens that a change in the growth rates of ISTC, η_j, appears as a part of the neutral progress, A_t. (**HINT: Need to include a structural interpretation of the neutral progress**).

Table 1 reports two volatility measures for technology (A_t and an aggregate Q_t), output (GNP, Y_t), consumption of nondurables and services (C_t), investment (I_t, including private and public investments in both equipment and structures, change in inventories, and durable goods), hours per worker (h_t), number of workers (N_t, variable LNS12000000 of BLS), and total hours worked ($L_t = h_t N_t$, index PRS85006033 of BLS). The panel shows the variances calculated according to a Hodrick-Prescott filter with a smoothing parameter of 1600, $HP \ln$, which isolates cycles shorter than 32 quarters. All variances are scaled by a factor of 10^4. The last column of the table, labeled relative, presents the ratio of variances before and after 1984.1.

Comparing the periods before and after 1984, the variance of neutral progress is three to four times smaller and the variance of investment-specific progress is two to seven times smaller. HP-filtered series show an increase in variance during the period 1974.1-1983.4 compared to previous post-war years. This is not the case for neutral progress at higher frequencies, i.e., for the $\Delta \ln$ filter. Following some authors, I consider the first quarter of 1984 the switching point (McConnell and Pérez-Quirós, 2000 and Stock and Watson, 2000).

The variance of the macroeconomic variables also decreases after 1984.1. The strongest moderation is viewed for GNP. When the Hodrick-Prescott filter is used in the decomposition, volatility increases slightly during the decade 1974.1-1983.4 compared to the period before the 1974 slowdown. These variances do not substantially vary after 1995.1 compared to those computed for 1984.1-1994.1 (i.e., from the great moderation to the new economy age). The higher the frequency isolated by the filter, the greater the reduction in volatility. Whether the moderation of the main macroeconomic variables is due to technology is a question I will deal with in later sections.

Table 1: Variance of technology and macroeconomic variables ($\times 10^4$)

Hodrick-Prescott, $HP \ln$	1948.1-2008.4	48.1-73.4	74.1-83.4	84.1-94.4	95.1-08.4	Relative
Neutral, A_t	1.04	1.28	2.04	0.42	0.30	4.20
Inv.-Specific, Q_t	1.17	0.84	4.38	0.12	0.38	6.83
Output, Y_t	2.98	3.99	5.24	1.02	0.87	4.71
Consumption, C_t	1.59	1.84	3.08	0.67	0.64	3.36
Investment, I_t	33.62	41.28	61.78	15.08	12.76	3.44
Hours p.w. h_t	0.99	1.19	1.04	0.84	0.70	1.53
Workers, N_t	1.01	0.97	2.42	0.53	0.48	2.73
Hours, $L_t = h_t N_t$	3.40	3.51	6.34	2.36	1.97	2.03

3 The model

Building on Greenwood, Hercowitz and Krusell (1997) we set up a dynamic general equilibrium neoclassical growth model featuring two key elements: the existence of different types of capital and the presence of technological change specific to each capital type. In particular, we follow Martínez, Rodríguez and Torres (2008) by distinguishing three types of capitals: structures, Non-ICT, and ICT equipment. Output Y_t is produced as a combination of four inputs: labor expressed in amount of hours worked, L_t; non residential structures, $K_{str,t}$; Not-ICT equipment $K_{nict,t}$; ICT equipment, $K_{ict,t}$. As mentioned in Section 2, the ICT equipment refers to hardware, software and communication networks, while Not-ICT equipment refers to machinery and transport equipment. Also, we assume that investment-specific technological innovations are embedded in ICT and Non-ICT equipment, but not in structures.

Households The economy is inhabited by an infinitely lived, representative household who maximizes a time-separable utility function defined in terms of consumption of final goods and hours worked, $U(C_t, L_t)$, i.e.

$$U(C_t, L_t) = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma} - 1}{1-\sigma} - \zeta \frac{L_t^{1+1/\nu}}{1+1/v} \right) \tag{5}$$

where C_t is the consumption level, L_t is time devoted to work, β is the time discount factor, ζ is a preference parameter affecting the substitution between consumption and leisure. Parameter v is the Frisch labor supply elasticity, and σ measures consumer's risk aversion.

The representative consumer holds a portfolio composed by three assets, which are the different types of capitals in the economy. He supplies labor services per unit of time and rents whatever capital he owns to firms. Labor and capital markets are perfectly competitive, with a wage W_t paid per unit of labor services and a rental rate $R_{j,t}$ paid per unit of capital j, for $j = \{ict, nict, str\}$. Under these assumptions, the representative agent's budget constraint can be written as

$$C_t + I_{str,t} + I_{nict,t} + I_{ict,t} = W_t L_t + R_{str,t} K_{str,t} + R_{nict,t} K_{nict,t} + R_{ict,t} K_{ict,t} \tag{6}$$

Capital assets evolve according to:

$$\begin{aligned} K_{ict,t+1} &= (1-\delta_{ict}) K_{ict,t} + Q_{ict,t} I_{ict,t} && (7) \\ K_{nict,t+1} &= (1-\delta_{nict}) K_{nict,t} + Q_{nict,t} I_{nict,t} && (8) \\ K_{str,t+1} &= (1-\delta_{str}) K_{str,t} + Q_{str,t} I_{str,t} && (9) \end{aligned}$$

where δ_j is the depreciation rate and $Q_{j,t}$ measures the amount of capital j than can be purchased with one unit of the consumption good. We assume $Q_{str,t} = 1 \checkmark t$, which implies no investment-specific technological change in structures, as usually assumed in standard neoclassical one-sector growth models,[7] while we let $Q_{i,t}$ for $i \in \{nict, ict\}$ to vary over time. Consistently with the series of technological change constructed in Section 2, we interpret an increase of $Q_{i,t}$ as a reduction in the average cost of production of investment goods in units of final good. Technology is assumed to evolve according to a dynamics that allow for mutual interactions of the different innovations. This point will be made clear in next Section 5 where we specify the processes for $Q_{j,t}$.

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[7] We use this as a simplifying assumption. Gort, Greenwood and Rupert (1999) estimate that the NIPA price for nonresidential structures should be quality adjusted by a 1% yearly.

The problem faced by the consumer is to choose the sequence $\{C_t, L_t, I_{nict,t}, I_{ict,t}, I_{str,t}\}_{t=0}^{\infty}$ to maximize the utility (5), subject to the budget constraints (6) and the laws of motion (7)-(9), given some initial conditions $K_{j,0}$.

Firms. As in the prototype RBC model, we assume that there is a single firm in the economy that produces a homogeneous good which is sold as consumption and investment goods. Both output and investment are measured in units of consumption. The firm fulfills all the demand from the household, and its profits maximizing problem reduces to choose the optimal combination of labor L_t and capital assets $K_{j,t}$ to produce Y_t. The technology of production is given by a standard Cobb-Douglas production function with constant return to scale, i.e.

$$Y_t = A_t L_t^{\alpha_l} K_{str,t}^{\alpha_{str}} K_{nict,t}^{\alpha_{nict}} K_{ict,t}^{\alpha_{ict}} \tag{10}$$

where A_t is the total factor productivity [henceforth, TFP], $0 \leq \alpha_j < 1$, $j \in \{str, nict, ict\}$, and

$$\begin{aligned} \alpha_{str} + \alpha_{nict} + \alpha_{ict} &< 1 \\ \alpha_l + \alpha_{str} + \alpha_{nict} + \alpha_{ict} &= 1 \end{aligned}$$

The Balanced Growth Path Equilibrium. The equilibrium outcome for this model economy is derived using the first order conditions of consumer and firm and imposing the standard market clearing condition in the goods market, that is, total production of goods must be equal to the sum of consumption and investment goods. We restrict out attention to the equilibria that exhibit a balance growth path, defined as an equilibrium where all variables grow at constant rates. In particular, output, consumption and investment will grow at the same rate γ, while the growth rate of the different types of capital will depend on the evolution of their relative prices. Labor, as usual in these models, is assumed to be constant. In our model economy, the balanced growth path requires that[8]

$$\gamma = \gamma_A g_{str}^{\alpha_{str}} g_{nict}^{\alpha_{nict}} g_{ict}^{\alpha_{ict}}$$

where g_i is the growth rate of capital i. Previous contidion can be fairly simplified noticing that in a balanced growth path equilibrium the laws of motion (7)-(9) imply that the growth rate of capital is

$$g_i = \gamma_i \gamma \tag{11}$$

for $i = \{ict, nict, str\}$. In addition, notice that $\gamma_{str} = 1$ because of the assumption of no specific technological progress in structures. Hence, the balance growth path equilibrium in our model implies that the growth rate of consumption, output, and investments is common and equal to

$$\gamma = \underbrace{\gamma_A^{1/\alpha_l}}_{\text{Neutral}} \times \underbrace{\gamma_{nict}^{\alpha_{nict}/\alpha_l} \gamma_{ict}^{\alpha_{ict}/\alpha_l}}_{\text{Investment-specific}} \tag{12}$$

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[8] The results follows immediately from the production function (10).

or, using a first order Taylor approximation,

$$\gamma \simeq \frac{1}{\alpha_l}\gamma_A + \frac{\alpha_{ict}}{\alpha_l}\gamma_{ict} + \frac{\alpha_{nict}}{\alpha_l}\gamma_{nict} \tag{13}$$

Expression (13) states that the growth rate can be decomposed into a linear combination of the growth of the different sources of technology, neutral ICT and Not-ICT. According to our results, structures $K_{str,t}$ and the interest rate $R_{str,t}$ will both grow at rate γ, while $K_{i,t}$ and $R_{i,t}$ will grow, respectively, at rate $\gamma_i\gamma$ and γ_i.

In order to find the balanced growth path equilibrium, it is convenient to express the model in terms of detrended variables. Assuming that γ satisfies equation (12) we know that exists a deterministic steady state where all the endogenous variables grow at constant rates. Denoting with $\widehat{S}_t = S_t/\Lambda_t$ the original variable S_t detrended by its trend Λ_t, and letting $\widehat{X}_t = \left\{\widehat{\lambda}_t, \widehat{C}_t, L_t, \widehat{Y}_t, \widehat{I}_{i,t}, \widehat{K}_{i,t}, \widehat{R}_{i,t}, \widehat{W}_t\right\}$ for $i = \{ict, nict, str\}$ and $\widehat{Z}_t = \left\{\log(\widehat{Q}_{ict,t}), \log(\widehat{Q}_{nict,t}), \log(\widehat{A}_t)\right\}$ respectively be the vector of all endogenous variables and the vector of the exogenous technological processes,[9] then a symmetric equilibrium for this model economy can be formally defined as the initial conditions $K_{j,0} \in \mathbb{R}_+$ and a process $\left\{\widehat{X}_t\right\}_{t=0}^{\infty}$

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[9] Given the assumptions made in our model, the vector Z_t evolves according to the dynamics estimated in (28) and $\varepsilon_t = \left\{\varepsilon_t^{Qict}, \varepsilon_t^{Qnict}, \varepsilon_t^{A}\right\}$ is a vector of i.i.d. normally distributed innovations.

that, given the exogenous stochastic process $\left\{\widehat{Z}_t\right\}_{t=0}^{\infty}$, satisfies the following system of equations:

$$\widehat{\lambda}_t = \widehat{C}_t^{-\sigma} \tag{14}$$

$$\zeta L_t^{\frac{1}{\upsilon}} = \widehat{W}_t \widehat{\lambda}_t \tag{15}$$

$$E_t\left[\frac{\widehat{\lambda}_t}{\widehat{\lambda}_{t+1}} \frac{\widehat{Q}_{ict,t}}{\widehat{Q}_{ict,t+1}}\left(1-\delta_{ict}+\widehat{Q}_{ict,t+1}\widehat{R}_{ict,t+1}\right)\right] = \frac{g^{\sigma}\gamma_{ict}}{\beta} \tag{16}$$

$$E_t\left[\frac{\widehat{\lambda}_t}{\widehat{\lambda}_{t+1}} \frac{\widehat{Q}_{nict,t}}{\widehat{Q}_{nict,t+1}}\left(1-\delta_{i}+\widehat{Q}_{nict,t+1}\widehat{R}_{nict,t+1}\right)\right] = \frac{g^{\sigma}\gamma_{nict}}{\beta} \tag{17}$$

$$E_t\left[\frac{\widehat{\lambda}_t}{\widehat{\lambda}_{t+1}} \frac{\widehat{Q}_{str,t}}{\widehat{Q}_{str,t+1}}\left(1-\delta_{str}+\widehat{Q}_{str,t+1}\widehat{R}_{str,t+1}\right)\right] = \frac{g^{\sigma}}{\beta} \tag{18}$$

$$\widehat{K}_{ict,t} = \frac{(1-\delta_{ict})}{\gamma_{ict} g} K_{ict,t-1} + \widehat{Q}_{ict,t}\widehat{I}_{ict,t} \tag{19}$$

$$\widehat{K}_{nict,t} = \frac{(1-\delta_{nict})}{\gamma_{nict} g} K_{i,t-1} + \widehat{Q}_{nict,t}\widehat{I}_{nict,t} \tag{20}$$

$$\widehat{K}_{i,t} = \frac{(1-\delta_{ict})}{g} K_{str,t-1} + \widehat{Q}_{str,t}\widehat{I}_{str,t} \tag{21}$$

$$\widehat{R}_{ict,t} = \alpha_{ict}\frac{\widehat{Y}_t}{\widehat{K}_{ict,t-1}}\gamma_{ict} g \tag{22}$$

$$\widehat{R}_{nict,t} = \alpha_{nict}\frac{\widehat{Y}_t}{\widehat{K}_{nict,t-1}}\gamma_{nict} g \tag{23}$$

$$\widehat{R}_{str,t} = \alpha_{str}\frac{\widehat{Y}_t}{\widehat{K}_{str,t-1}} g \tag{24}$$

$$\widehat{W}_t = \alpha_l \frac{\widehat{Y}_t}{L_t} \tag{25}$$

$$\widehat{Y}_t = A_t L_t^{\alpha_l} \prod_i \left(\widehat{K}_{i,t}/\gamma_i\right)^{\alpha_i} g^{\alpha-1} \tag{26}$$

$$\widehat{Y}_t = \widehat{C}_t + \sum_i \widehat{I}_{i,t} \tag{27}$$

Condition (15) is the standard labor supply, which is interpreted as equating the marginal rate of substitution between consumption and leisure to the opportunity cost of one additional unit of leisure. Conditions (16)−(18) represent the three Euler Equations, which state that the inter-temporal marginal rate of consumption must equate the rates of return for each of the three investment assets. On the aggregate supply side, conditions (22) − (25) give the optimal policy of the firm, who hires capital and labor until the marginal productivity of each factor equates its competitive rental price, and condition (26) represents firm's production function. Finally, we impose the standard market clearing condition (27) on the goods market. The system of equations (14) − (27) characterizes the competitive equilibrium for this economy.

It is worth noticing that the role of capital in the model economy defined above is symmetric for the three capital assets considered. If some capital has an impact on endogenous variables different from the others, this will be exclusively due to a different calibration of its law of motion or in the process of the corresponding technological change. In particular, we assume no externality of investing in ICT versus structures or Not-ICT, as other papers in the literature do.[10] In this perspective our results are conservative in the sense that the assessment on the contribution of ICT technology to aggregate fluctuations will constitute a lower bound of the actual contribution, since it capture only direct effects.

4 Technology and growth (keep? drop?)

According to the neoclassical growth model, long run productivity growth can only be driven by the state of technology. In our framework, we can decompose long-run labor productivity growth into three different technological factors: neutral change, non-ICT equipment investment and ICT equipment investment.

Table 2 decomposes the US productivity growth into these sources of technology. The first column reports the results for the whole perio, 1948:1-2008:4, and four sub-periods, splitting the sample according to the following key years: the 1974 productivity slowdown (Greenwood and Yorukoglu, 1998), the great moderation year of 1984 (McConnell and Pérez-Quirós, 2000; Stock and Watson, 2000), and the acceleration from the new economy of 1995 (see Hansen, 2001, for structural break tests; or see Cummins and Violante, 2002 and Jorgenson and Stiroh, 2000, who have stressed the importance of the ICT behind the resurgence in US productivity after 1995).

In view of these results, we highlight the following facts. *First*, neutral technological change accounts for 63% of the long run productivity growth in the US. The remaining fraction is accounted for by the ISTC. This is significantly smaller to the estimate given by Greenwood et al. (1997), where the ISTC accounts for 58% of total growth in a shorter period. The difference in these results can be explained on the the calibration of the labor income share α_L. However, the role ISTC in accounting for productivity growth has incresed over time, mainly after the 1974-slowdown.

Second, technology embedded in the ICT assets is a very important source of the investment-specific change in the US economy. However, the non-ICT ISTC equipment also have a non negligible contribution to economic growth. The investment specific change associated to the ICT equipment doubles that of the non-ICT equipment.

And *third*, both the fall in productivity in 1974 and its recovery in the mid nineties can be explained in view of the evolution of the neutral progress. For example, comparing the second and the third columns (48-73 vs. 74-83), we find thta the fall in productivity was motivated by a dramatic decline in the growth rate of the neutral progress, that accompanied a timid revival of the growth prompted by the ISTC. Yet comparing the last two columns (84-94 vs. 95-08), we find that the productivity recovery was due to the recovery in the neutral progress. This result contradicts those found in some other papers like Collechia and Schreyer (2001), or Jorgenson and Stiroh (2000), where the ICT was made responsible in the upsurge in the U.S. productivity growth during the nineties.

Our conclusion, though, shold not be viewed as an attempt to reduce the importance of ICT assets, or the ISTC therin, in explaining US long run productivity growth. Rather Table 2 points out to the fact that it has been an important contributor (a quarter of productivity growth can be accounted

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[10] Put references.

for the ICT-ISTC after 1995). However, the change in the sign of the evolution of productivity is a phenomena that should be associated to the neutral progress.

5 Technology and fluctuations

5.1 Calibration

The model has 4 preferences parameters $\{\beta, \sigma, v, \zeta\}$, which are stable over the two samples, and 6 technology parameters $\{\delta_{ict}, \delta_{nict}, \delta_{str}, \alpha_l, \alpha_{ict}, \alpha_{nict}, \alpha_{str}\}$ plus the parameters that characterize the distributions of technology processes, that are calibrated differently for the two samples.

$\boldsymbol{Table3 : Calibration}$

Parameter	1948 - 1974	1984 - 2008	Description
β	0.991	0.991	Subjective discount factor
σ	2	2	Relative Risk Aversion
v	3	3	Frish elasticity of labor
ζ	25.0	24.4	Preference parameter
δ_{ict}	0.053	0.043	Depreciation rate of ICT
δ_{nict}	0.030	0.028	Depreciation rate of Non-ICT
δ_{str}	0.006	0.006	Depreciation rate of Neutral tech.
α_l	0.705	0.710	Labor share
α_{ict}	0.013	0.043	ICT capital share
α_{nict}	0.083	0.061	Non-ICT capital share
α_{str}	0.196	0.185	Structure capital share
γ_{ict}	1.007	1.019	Growth rate of ICT
γ_{nict}	1.008	1.010	Growth Rate of Non-ICT
γ_a	1.005	1.001	Growth Rate of Neutral tech.
g	1.008	1.003	Balanced growth rate

Structural parameters are calibrated as follows. Following the standard real business cycle literature, the discount parameter β is chosen such that yearly nominal interest rate in the model is about 4%, the risk aversion parameter σ is set equal to 2, and the Frisch elasticity of labor supply v is set equal to 1/3, an average value between macroeconomics and microeconomics calibrations. The preference parameter ζ is chosen to ensure that in steady state the consumer devotes 1/3 of his time to labor activities.

Technology parameters are calibrated as follows. The depreciation rates $\{\delta_{ict}, \delta_{nict}, \delta_{str}\}$ are chosen according to ... [JESUS]. The shares of capitals $\{\alpha_{ict}, \alpha_{nict}, \alpha_{str}\}$ are fixed such that in the steady state the investment shares of Structures, ICT, and Non-ICT over GDP match the average of its counterpart in U.S. data over each sample period.[11] Finally, α_l is fixed residually to fulfil the condition $\sum_j \alpha_j = 1$.

Finally, the parameters that of the shocks distributions are calibrated as follows. The growth trends $\{\gamma_i, \gamma_n, \gamma_a\}$ are obtained applying a linear filter to the log of our data on $\{Q_{ict,t}, Q_{nict,t}, A_t\}$, while the

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[11] Put references of the data used.

coefficients of the autoregressive processes are taken from the estimates of the VAR model (28). Table ?? summarizes the set of calibrated parameters.

5.2 Results

In this section we make use of the DSGE model presented in Section 3 in order to quantify the contribution of the different technology sources to the aggregate variables fluctuations. To this end, we first calibrate the dynamics of TFP and investment-specific technological change in the DSGE model equal to their counterparts in the data; then, we simulate the resulting model.

To extract the underlying stochastic process of shocks that generate the technological change observed in the data, we fit a Vector AutoRegression (VAR) model to the series of technology $\{Q_{ict,t}, Q_{nict,t}, A_t\}$. The VAR model poses few structure on the dynamics of technological change and it is aimed to capture cross effects among TFP, ICT, and Non-ICT. In details, we estimate the following VAR

$$Z_t = a \cdot \mu + \sum_{j=1}^{p} B_j \cdot Z_{t-j} + d \cdot tr_t + \varepsilon_t \tag{28}$$

with

$$Z_t = \left[\begin{array}{ccc} \ln Q_{ict,t} & \ln Q_{nict,t} & \ln A_t \end{array} \right]'$$

where μ_t is a vector of constant terms, tr_t is an exogenous time trend, $\{a, B_j, d\}$ are the reduced form coefficients of the VAR, and ε_t is the vector of normally distributed errors with zero mean and variance-covariance matrix $\Sigma = E\left(\varepsilon_t \cdot \varepsilon_t'\right)$.

According with our purposes, data are split into two subsamples: $1948.1 - 1974.1$ and $1984.1 - 2008.4$, respectively of 103 and 99 observations. The series of technology are taken in log-levels and a linear time trend is extracted to wash out long run components. The resulting cyclical components are assumed to be covariance stationary. The order p is chosen to be the minimum order of lags for the VAR residuals to be not serially correlated. In both samples $p = 2$ lags are sufficients for the VAR residuals to have no autocorrelation up to the 7th order.[12] These conditions assures that the VAR(p) estimates are consistent.

The Maximum Likelihood estimation of the VAR (28) delivers one main insight: the dynamics of the three processes appear to change significantly between the two samples. Specifically, the series of the TFP appears to be an univariate autoregressive process [henceforth, AR] of order 1 in the first sample, as usually assumed in the RBC literature,[13] while it becomes a multivariate process in the second sample, when both the coefficients on lagged $Q_{nict,t}$ appear highly significant. This result can be interpred as an evidence that technological change in Non-ICT use to increase the TFP during the last 20 years, i.e., an innovation to equipment and machinery raises not only the productivity of capital, but also the one of labor, possibly due to complementarities between equipments and labor in the production function. The process of technological change in Not-ICT sector also exhibits a changing dynamics, going from

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[12] We choose the minimum order of lag to be used in the VAR using Akaike's information criterion (AIC), Schwarz's Bayesian information criterion (SBIC), and the Hannan and Quinn information criterion (HQIC). Then, after the estimation we test for the presence of autocorrelation in the residuals with a standard LM test.

[13] Based on our estimated coefficients, the hypothesis that $A_t \sim AR(1)$ is not rejected at any significance level.

a full multivariate process (where all the coefficients are significant) to an AR process of order 2. The dynamics of technological change to ICT sector instead appears not to change over the two samples and featuring the same univariate AR process of order 2.

[Should we introduce here an analysis of persistence in the VAR?]

A crucial calibration required to simulate the DSGE model is the one of the variance of exogenous shocks. The prediction errors from the reduced form VAR (28), however, do not seem the appropriate candidates to proxy for exogenous shocks because they appear to be contemporaneously correlated with each others. This evidence implies that a shock in one sector may affect the other sectors not only through the lagged dynamics of the VAR, but also by triggering technological innovations in the other sectors. Such an evidence is not surprising. Suppose, for instance, that an innovation occurs in ICT. This could increase the productivity of Not-ICT capital both with a direct effect (examples...) and by stimulating innovations in Not-ICT sector, which would arise in order to better exploit the new ICT technology. A reduced form VAR as the one estimated above would only capture the first effect, but not the second. Hence, we estimate a structural VAR model (SVAR) and use innovations from this model as proxy for the exogenous shocks. The SVAR model is estimated twice using two alternative sets of assumptions to achieve identification. The first specification assumes that innovations to ICT and Not-ICT are independent and both affect shocks to TFP. The second specification assumes that innovations to ICT and TFP are independent and both affect the Not-ICT investment-specific shocks.

There are two insightful results from the SVAR model, and we shall explore them in turn. First, the identification assumption that ICT and Not-ICT innovations affect the shocks to TFP is accepted at any significance level in both samples.[14] This finding suggests that the TFP process should be retrieved from the data jointly with the investment-specific technological change and not by itself alone using a univariate process, as usually done in the RBC literature. On the contrary, the alternative assumption that ICT sector and Neutral technology innovations affect Not-ICT investment-specific shocks is only accepted in the first sample but not in the second.[15]

Regarding the estimated variances of the shocks from the SVAR model, our results are consisten with the recent literature on the Great Moderation.[16] We find that the standard deviation of A_t goes from 0.008 in the first sample, which coincides with the usual value calibrated in the RBC literature, to 0.0041 in the second sample. The variance of the shocks to $Q_{ict,t}$ also reduces significantly, passing from 0.0121 to 0.0055. Differently, the variance of the shocks to Not-ICT sector exhibits a constant value over the two samples, i.e., 0.0049 vs 0.0050. To understand the actual changes in the contributions of the different technologial sources on the technology processes, we complement this analysis with the variance decomposition in the estimated SVAR.

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[14] Identification assumptions in the SVAR are tested using a LR test of the Null hypothesis that all the empty cells in the Orthogonalization matrix are significantly equal to zero. These results together with the tables of the estimated VAR and SVAR models are available from the authors upon request.

[15] From side estimations, we also learn that the shocks to ICT are independent from other shocks in both subsamples.

[16] Put references.

[Variance Decomposition in the SVAR]

We now consider a log-linear approximation of the model's policy functions in a neighborhood of the non-stochastic steady state. Rational expectations are solved to obtain the dynamic responses of the endogenous variables as functions of the state variables. We characterize the quantitative response of model variables to the three technology shocks, namely: the neutral technology shock (figure **??**), the ISTC shock to ICT (figure **??**), and the ISTC shock to ICT (figure **??**).[17]

As apparent from figure **??**, a positive shock to neutral progress, $\varepsilon_{a,t}$, has a positive impact on output by raising total factor productivity A_t, which in turn increases both labor revenues and capital revenues. Consumption and total investment also increase increase due to the positive income effect. The response of hours also is positive, as in the standard RBC model, and the magnitude of the increase in productivity (prm) depends mainly on the Frisch labor supply elasticity. The higher this elasticity, the higher the response of labor to an increase in wage. In our calibration, the positive response of output is larger than the one of labor, and therefore productivity increases after $\varepsilon_{a,t} > 0$. Finally, notice that $\varepsilon_{a,t}$ does not affect the dynamics of the ISTC shocks, and therefore the different amplitude in the responses of the three investment goods depends entirely on the different calibration of the depreciation rates for the three capital assets. Overall, the aggregate dynamics after a neutral technology shock resembles closely the one of the standard one capital RBC model.

Figure **??** plots the IRF after a positive ISTC shock to ICT. Several effects of this shock of the aggregate dynamics are worth noticing. First, given the matrix of identification estimated from the SVAR (see section 2), $\varepsilon_{a,t} > 0$ implies a contemporaneous reduction in A_t, and this in turns drive the negative response at impact of output, consumption, and hours. About this last, the negative response of labor implies that the substitution effect (lower wage) is stronger than the income effect, and therefore hours diminishes. However, notice that the overall effect on hours is of one order magnitude lower than the one of output, and thus productivity also descreases. Second, the responses of investment goods at the impact have opposite sigh with respect to the following period when, as expected, there is a positive investment in ICT and in Non-ICT goods. Notice that this last response is due to the positive coefficient of the lagged ICT in the Non-ICT dynamics. The responses of investments at impact instead look puzzling because investment in ICT and Non-ICT decreases, while investment in structure increases even though the rental rate of structure decreases consistently with the reduction of A_t. This counterintuitive result can be explained with the portfolio reallocation of the household, who wants to equate the marginal benefits from the three capital assets. Since the depreciation rate of the structures is much lower than the one of ICT and Non-ICT, 0.006 versus respectively 0.043 and 0.028, then the opportunity cost of producing today structures for future periods is much higher than the one of anticipated production of ICT or Non-ICT goods. In our simulated model, this future marginal benefit more than compensate the actual marginal loss from the reduction in the interest rate, and therefore drive the positive response of investment in structure.

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[17] The figures refers to the aggregate dynamics of the model calibrated to match the economy in the second sample, i.e. 1984 - 2008. There are, however, no qualitative difference with respect to the IRF of the first sample, and the corresponding figures are available from the authors upon request.

Finally, figure **??** plots the IRF after a positive ISTC shock to Non-ICT. The aggregate dynamics in this case mimics closely the one analyzed after a shock to ICT. The only difference is that now investment in ICT goods is crowded out both at impact and in the following periods. This finding is not specular with previous case, and it can be explained by comparing the different dynamics of ICT and Non-ICT processes as estimated in the VAR. Non-ICT technological change does not affect ICT technological change, neither at impact (orthogonalization matrix), not in the lagged terms (reduced form coefficients of the VAR), while the opposite is true. Actually, in figure **??** the degenerated IRF of $Q_{ict,t}$ is missing because equal to zero in all periods. Hence, the effect of $\varepsilon_{nict,t}$ never affects the productivity of ICT capital, which therefore diminishes in relative terms thus implying the observed disinvestment.

As final consideration, notice that our model predicts that only neutral technology shocks have a positive effect on total investment at impact, while ISTC shocks have negative effects as usually encountered in this literature. Thus, our model preserves the identification strategy based on the sign restrictions of IRF broadly employed in the papers that estimated DSGE models with ISTC shocks.

Table 5 reports the unconditional variances calculated by simulating the DSGE model for the two periods at interest, 1948.1-1974.1 and 1984.1-2008.4. In each period, model parameters are calibrated as explained in previous section, while the dynamics of the three the technology processes is set equal to the correspondent estimated equation $\{Q_{ict,t}, Q_{nict,t}, A_t\}$ in the VAR. The variances of the exogenous shocks are calibrated according to the results of the SVAR model mentioned above. The unconditional variances of fitted variables are decomposed in order to disentangle the contributions of the different sources of technology. Our goal is to understand the contribution to volatility of TFP versus investment-specific technical change, and in particular of ICT. In the following, we only focus on the three endogenous variables at interest, i.e., productivity and its components (output and worked hours).

Table 5: Variance Decomposition of fitted variables

	Output		Productivity		Worked Hours		Total Investment	
	48.1-74.1	84.1-08.4	48.1-74.1	84.1-08.4	48.1-74.1	84.1-08.4	48.1-74.1	84.1-08.4
Variance * 10^4	3.65	1.00	0.49	0.13	1.46	0.41	126.5	34.81
Variance Decomposition	Contribution (%)		Contribution (%)		Contribution (%)		Contribution (%)	
Neutral	83	66	87	62	80	69	74	73
Inv-Specific	17	34	13	38	20	31	26	27
ICT	2	6	2	4	2	6	3	8
No-ICT	15	28	11	34	18	25	23	19

Results from table 5 show that the contribution of neutral shocks to productivity, output, and labor variances diminishes sensibly in the second sample, possibly due to the decrease in its own volatility. Specularly, the contribution of investment-specific shocks raises, in particular the one of ICT which more than double. This finding is in line with the widespread opinion that ICT gained importance in determining the behavior of productivity during last years. However, contrarily to what we could expect, the raise in the contribution of Not-ICT increased even larger than the one of ICT. The weight of this last as source of fluctuations relative to Not-ICT, which we measure with the ratio of the contribution of ICT versus Not-ICT, decreased from 0.8 to 0.48 for productivity, from 0.5 to 0.29 for output, and from 0.3 to 0.27 for labor. Our intuition of this result rely on the behavior of the variance of Not-ICT shocks over the two samples. Compared with the other two sources of technological change, only the variance of Not-ICT shocks did not diminish from one sample to the other. Notice that, because of this behavior of the relative variances, we could observe an increase of importance of Not-ICT shocks as source of fluctuations regardless the actual importance of Not-ICT in total productivity, but just because this type of shocks is relatively more volatile nowadays than it was before.

In order to gauge the impact of ICT capital in the aggregate economy, in table 6 we present some selected moments from U.S. data and we compare them with their counterparts from the model. We first analyze ability of the model to reproduce the volatility of macroeconomic aggregates (column 2) and then we present the results from a counterfactual exercise where we shut down all shocks but one at a time to observe the contribution to volatility of each single shock (columns 3 - 6).

Results in table 6 show that the model with all shocks active is able to reproduce well the volatility of output in both subsamples, fitted standard deviation of output is 104% of the one in data in first sample and 98% in the second sample, and the model capture well the reduction in volatility between the two samples. This is clearly due to the exogenous change in the distributions of shocks and technological processes borrowed from VAR. The interesting result, though, is that the reduction in the volatility of fitted productivity, labor, and output accounts − actually overaccounts − for the whole reduction observed in actual data. This finding can incidentally support the theory that the Great Moderation of the last 20 years could be due entirely to "luck", i.e., to a change in the volatility of the exogenous shocks.[18] This last results holds true for all the variables considered, even though the model has some problem in reproducing the volatility of worked hours and therefore the one of productivity. This finding is well know in the literature of the RCB, where several papers pointed out that the standard one sector neoclassical growth model cannot account for the observed volatility of labor when we calibrate the Frish elasticity of labor supply to the value suggested by microeconomic evidence. Total investment, which is defined in the model as the sum of investment in ICT, Non-ICT, and structures, is sensibly less volatile than in the data. This is due to the negative correlation among fitted investments compared to the positive corrrelation encountered in the data.

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[18] Put reference.

Table 6: Predicted versus Observed Volatility.

Linear Filter	Sample	Data	All shocks	Neutral	Both	only	only
Standard Deviation (%)					ISTC	Non-ICT	ICT
Output	48.1-74.1	3.00	3.12	3.00	0.87	0.96	0.21
	84.1-08.4	1.79	1.77	1.24	1.28	0.84	0.85
Worked Hours	48.1-74.1	2.8	0.96	0.91	0.28	0.28	0.07
	84.1-08.4	3.28	0.59	0.40	0.43	0.34	0.27
Productivity	48.1-74.1	1.63	4.66	4.51	1.27	1.20	0.29
	84.1-08.4	2.50	2.36	1.72	1.64	1.14	1.18
Total Investment	48.1-74.1	12.92	1.54	1.43	0.54	0.53	0.13
	84.1-08.4	12.67	1.23	0.80	0.94	0.78	0.52
Consumption	48.1-74.1	2.46	1.93	1.88	0.48	0.47	0.12
	84.1-08.4	2.13	0.81	0.64	0.51	0.28	0.43

Table 7: Predicted versus Observed Volatility.[19]

HP Filter	Sample	Data	All shocks	Neutral	Both	only	only
Standard Deviation (%)					ISTC	Non-ICT	ICT
Output	48.1-74.1	1.99	1.91	1.57	1.04	1.00	0.31
	84.1-08.4	0.97	1.00	0.87	0.49	0.39	0.30
Worked Hours	48.1-74.1	1.88	1.21	0.98	0.67	0.65	0.20
	84.1-08.4	1.46	0.64	0.56	0.31	0.24	0.20
Productivity	48.1-74.1	1.21	0.70	0.59	0.37	0.36	0.11
	84.1-08.4	0.79	0.36	0.31	0.19	0.15	0.10
Total Investment	48.1-74.1	10.22	11.25	8.97	6.37	6.17	1.89
	84.1-08.4	5.54	5.90	5.17	2.75	2.05	1.87
Consumption	48.1-74.1	1.36	0.35	0.31	0.16	0.18	0.05
	84.1-08.4	0.87	0.15	0.10	0.10	0.10	0.03

6 Concluding remarks

This paper investigates the contributions of different sources of technological progress to US GNP growth and its volatility. we have used a DSGE model that decomposes productivity growth into two sources of technological progress: neutral and investment-specific change. The first type of progress refers to changes affecting total factor productivity, and the second type refers to changes in the quality of investment goods.

The conclusions are as follows. US long run growth has been led by investment-specific progress and its contribution has increased over time, insomuch as this progress has accelerated. Most of the deviations in output and investment from the balanced growth path have been caused by shocks to neutral progress. However, shocks to investment specific technological change account for an important

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[19] Reported Standard Deviation in tables 6 and 7 are the mean of standard deviations of fitted variables, each series of 1000 periods, simulated 500 times.

fraction of the variability in consumption and hours. This finding applies to both unconditional and conditional variances. Third, when changes affecting the representations of technology in 1974 and 1984 are taken into account, the role of shocks to investment specific progress increases over time for all variables. we also conclude that the moderation in volatility of the macroeconomic series can be primarily explained through technology arguments.

These findings suggest that the nature of growth and fluctuations has changed as the essence of technology has evolved over the past three decades.

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A Tables

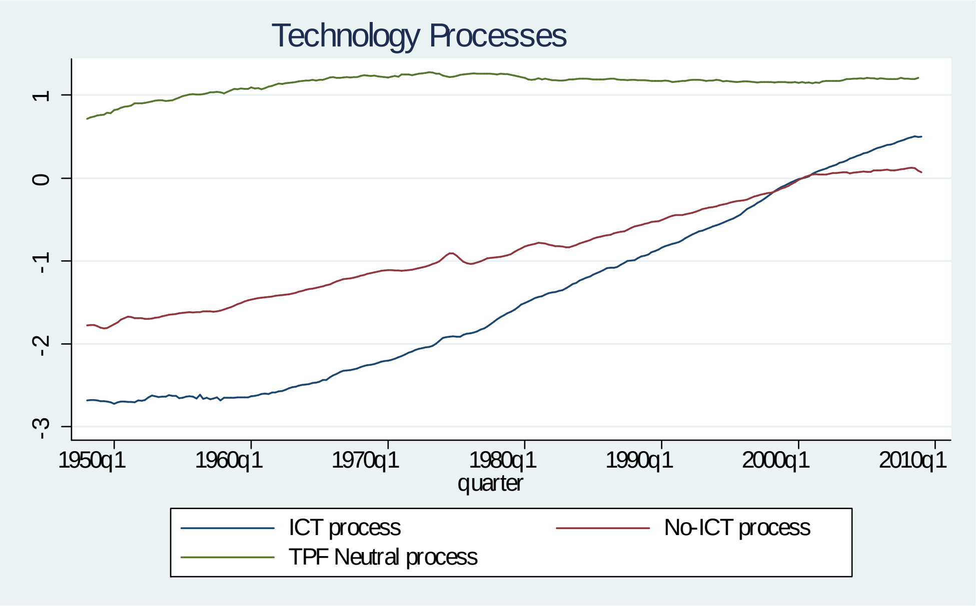
Table 1: Investment Specific Technical Change by Asset, U.S.A. 1977-2006

	77-06	77-80	80-90	90-00	00-06
All equipment	**5.8**	**2.6**	**5.5**	**7.0**	**5.7**
Non-ICT equipment	3.5	0.0	3.5	4.0	4.3
(i) Transport equipment	*3.8*	*2.6*	*3.3*	*4.6*	*4.1*
(ii) Machinery equipment	*3.1*	*2.0*	*2.2*	*3.7*	*4.5*
(iii) Other equipment	*2.2*	*0.1*	*2.0*	*2.5*	*2.9*
ICT equipment	10.9	14.0	10.6	12.3	7.7
(iv) Hardware equipment	*19.1*	*30.1*	*15.6*	*22.1*	*14.3*
(v) Communication equipment	*12.4*	*17.6*	*9.0*	*13.8*	*13.2*
(vi) Software	*4.2*	*5.2*	*4.9*	*4.1*	*2.6*

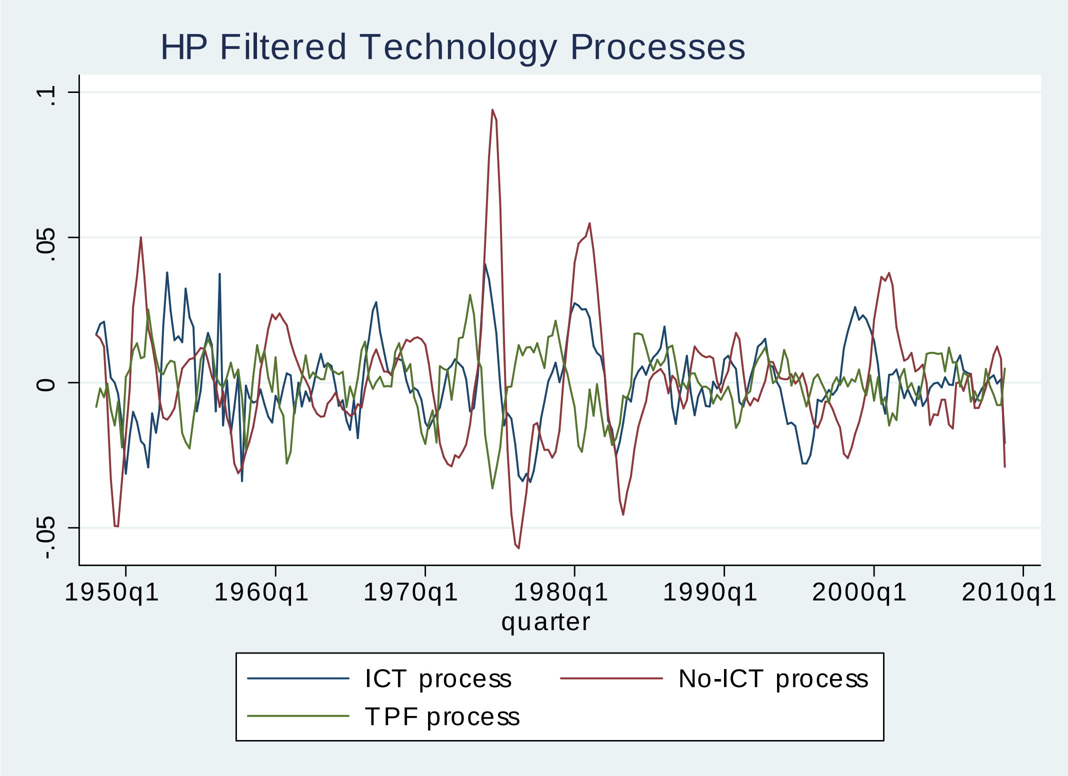
Table 2: Decomposition of productivity growth by technological sources

		1948:2008:4	48:1-73:4	74:1-83:4	84:1-94:4	95:1-08:4
Growth rates	Non-ICT ISTC	3.1	3.0	2.0	4.6	2.9
	ICT ISTC	5.3	2.9	7.2	6.9	7.4
	GDP (a)	3.0	4.0	2.1	2.6	2.2
	Hours (b)	1.2	1.4	1.3	1.8	0.6
	Productivity (a-b = c+d)	1.8	2.7	0.8	0.7	1.7
	TFP (Calibrated)	0.8	1.6	0.1	-0.1	0.7
Decomposition	Neutral (c)	1.13	2.17	0.17	-0.13	0.93
	ISTC (d)	0.64	0.48	0.65	0.87	0.74
	Non-ICT	0.31	0.30	0.19	0.44	0.28
	ICT	0.34	0.18	0.46	0.43	0.46
	Neutral	63.62	81.87	20.53	–	55.68
	ISTC	36.38	18.13	79.47	–	44.32
	Non-ICT	17.23	11.25	23.68	–	16.74
	ICT	19.15	6.87	55.80	–	27.58

B Figures


Technology Processes
1
0
-1
-2
-3
1950q1
1960q1
1970q1
1980q1
1990q1
2000q1
2010q1
quarter
ICT process
No-ICT process
TPF Neutral process

]


HP Filtered Technology Processes
.1
.05
0
-.05
1950q1
1960q1
1970q1
1980q1
1990q1
2000q1
2010q1
quarter
ICT process
No-ICT process
TPF process

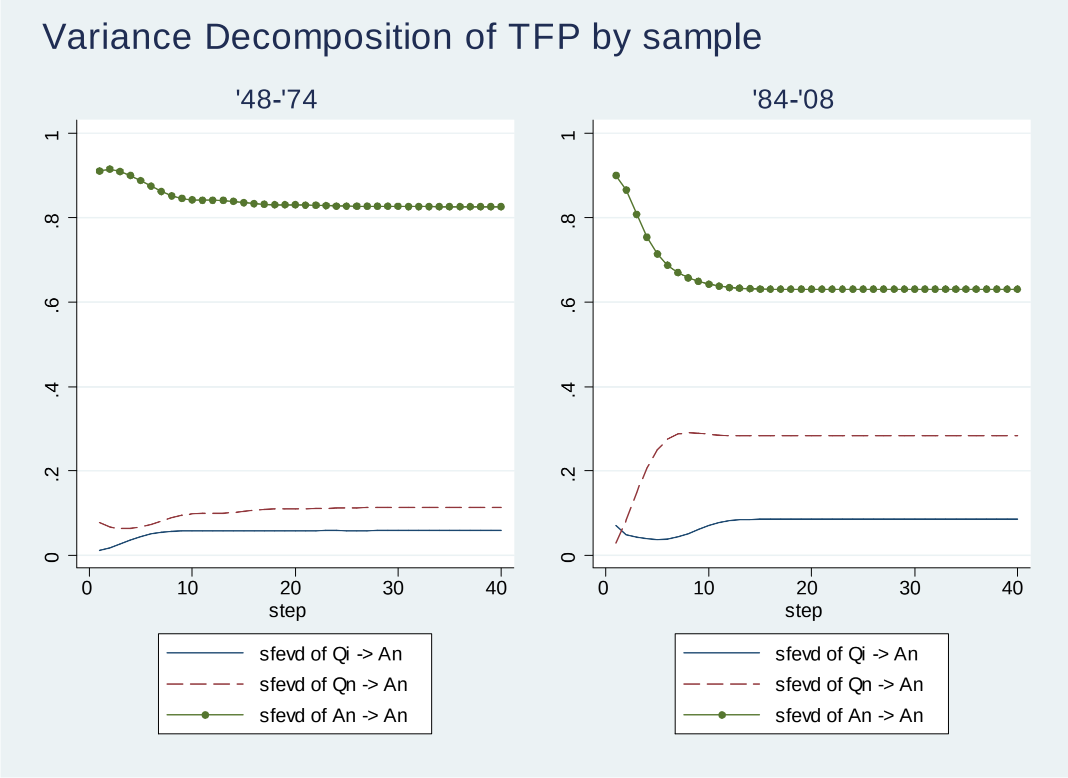

Variance Decomposition of TFP by sample
'48-'74
'84-'08
1
.8
.6
.4
.2
0
0
10
20
30
40
step
sfevd of Qi -> An
sfevd of Qn -> An
sfevd of An -> An

Figure 1: Impulse Response Functions to a 1% orthogonalized shock. Sample 2

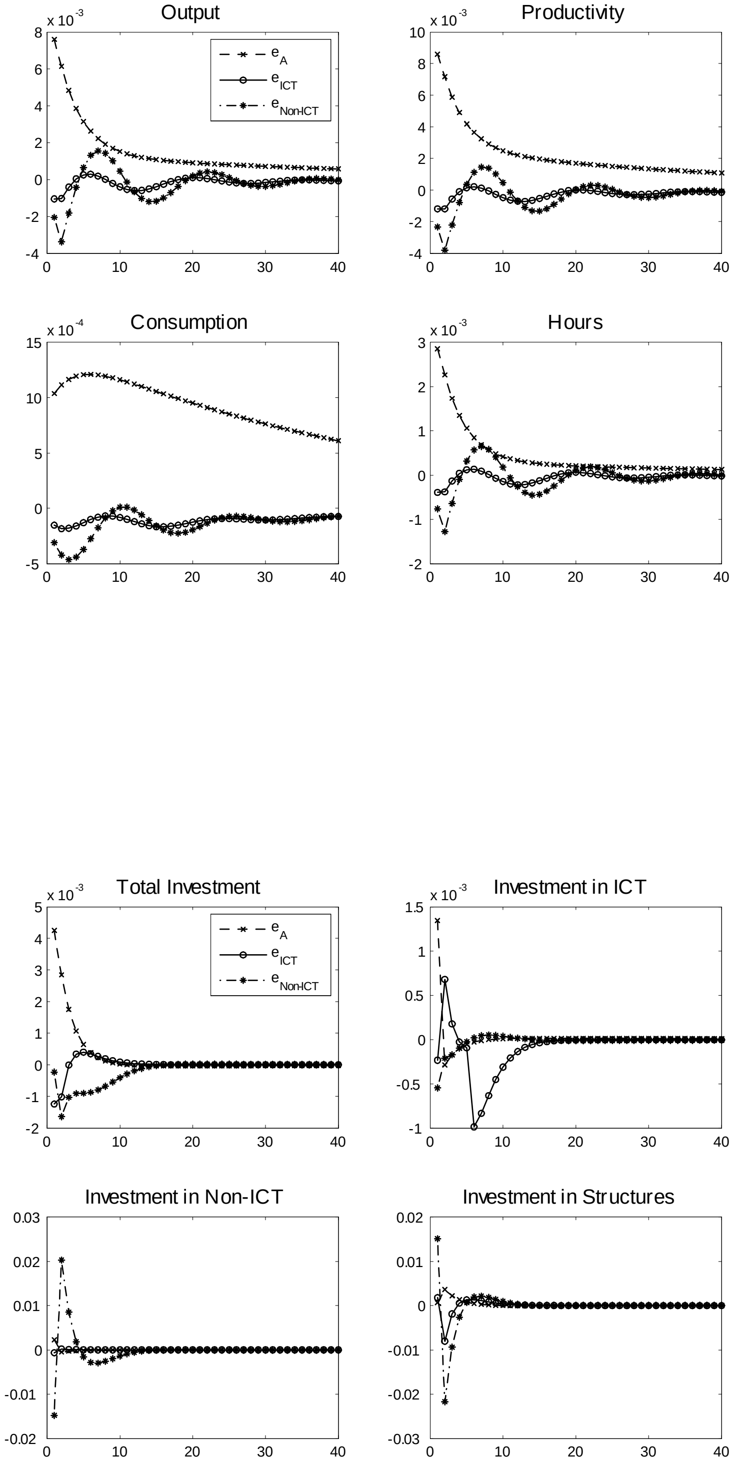


Figure 2: Impulse Response Functions to a 1% orthogonalized shock. Sample1