

# ICT and Future Productivity: Evidence and Theory of a GPT\*

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## **Abstract**

Information and Communication technology (ICT) is able to explain accelerations in productivity in sectors that are ICT users. We employ Structural VARs to investigate the effects of ICT supply shocks on Total Factor Productivity (TFP) and other macroeconomic variables. In response to this sector-specific supply shock relative prices of ICT goods and services immediately fall, ICT investment rises on impact, and TFP displays a significant delayed and persistent increase. In line with theories of ICT as a general-purpose technology, we analyze a two-sector general equilibrium model in order to rationalize previous results and estimate key parameters via impulse-response matching. We conclude that ICT accumulation is able to enhance productivity through a positive spillover effect which takes into account the overall level of diffusion of ICT capital in the economy.

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# 1 Introduction

Although there is large consensus on the importance of productivity as a driver of economic performances, less agreement is on the underlying sources that enhance its growth. For several years most of the business-cycle literature purposely decided to avoid such a question by proxying movements in productivity as random shocks.<sup>1</sup> However, the robust empirical evidence of the slowdown in productivity right before the great recession is summoning the literature to take a step back and devote more attention on the drivers of medium-term productivity growth.<sup>2</sup>

Along with Comin and Gertler (2006), some theoretical contributions rationalize endogenous productivity dynamics by adapting features of endogenous growth models into DSGE models. Following Romer (1990), most of those papers augment final-good production functions with an expanding composite of intermediate goods produced by the R&D sector in order to allow for an endogenous rate of adoption of new technologies.<sup>3</sup> Consistent with those previous models, other papers attempt to provide empirical evidence of a slowdown in the productivity of the R&D sector. Specifically, they show that although research effort is keeping rising, the rate of new ideas and discoveries is slowing down.<sup>4</sup>

Motivated by this wave of research, this paper follows a different path and argue that Information and Communication Technology (hereafter ICT) plays an important role in driving medium-term productivity in sectors that are ICT users. Our contribution is twofold. First, we provide a robust empirical evidence to show that current rises in ICT investment explains significant and persistent increases in future Total Factor Productivity (hereafter TFP). Second, we analyze a standard theoretical framework in order to both motivate and rationalize our empirical results.

Regarding the empirical section, the idea is to identify technological shocks which are only specific to the ICT sector in a Structural VAR context.<sup>5</sup> In order to have a reliable

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<sup>1</sup>Kydland and Prescott (1982) and Long Jr and Plosser (1983) are among the first papers which consider productivity shocks on general equilibrium models.

<sup>2</sup>See Cette et al. (2016) and Byrne et al. (2016) among others.

<sup>3</sup>Bianchi et al. (2014), Anzoategui et al. (2016), and Moran and Queralto (2017) use similar techniques to endogenize growth. In particular, Bianchi et al. (2014) augment a DSGE model using a quality ladders model in the vein of Grossman and Helpman (1991). Moreover, Anzoategui et al. (2016) and Moran and Queralto (2017), similarly to Comin and Gertler (2006), use a model of expanding variety in the vein of Romer (1990).

<sup>4</sup>Jones (2009) and Bloom et al. (2017) are two important contributions that highlight those facts.

<sup>5</sup>An interesting paper which is somehow related to our empirical part is Jafari Samimi and Roshan (2012). The authors identify ICT shocks as a potential driver of the Iranian business cycle using a

identification procedure our multivariate system needs to embody three key variables: TFP, ICT investment (hereafter ICTI), and relative prices (hereafter RP). Importantly, ICTI is defined as the total expenditure in equipment and computer software meant to be used in production for more than an year. Thus, an increase in ICTI has to be thought as an ICT capital deepening. Moreover RP is the ratio between prices in the ICT sector over prices in the overall economy. To verify that we are correctly identifying an ICT technology shock, we firstly expect it to be orthogonal to the productivity of all the other sectors. Since the share of the ICT sector accounts for a negligible part in the whole economy we expect it should have an approximately zero effect on TFP on impact. Moreover, as pointed out by Greenwood et al. (1997) and Fisher (2006), embodying RP and ICTI is important because we expect that a sectoral technology shock should decrease its relative prices and enhance expenditure in the underlying sector.<sup>6</sup> In response to this shock, ICTI rises on impact and remains significant for several quarters. RP persistently and significantly declines for more than two years and TFP, which does not react on impact, rises after few quarters and remains significant and stable for at least 5 years.

Although our results are robust over different specifications, there is an important critique that our empirical strategy had to carefully take into account, which is the reverse causality due to news on future TFP. A well-taken concern motivated by the news-shock literature is that the positive reaction of ICTI on impact may be triggered by signals related to future increases in TFP and not to contemporaneous ICT technological improvements. In other words, our identification strategy may confound a news shock which contemporaneously enhances investment in ICT capital goods. In order to take into account this potential issue, we provide a series of robustness checks where sequentially we firstly identify a news shock in the spirit of Barsky and Sims (2011) and subsequently we identify our sectoral ICT shock using the previous identification strategy. Encouragingly, controlling for signals regarding future movements in TFP does not affect any conclusion drawn so far. In particular, we can now state even more strongly the causality relation from movements in current ICT technological changes to future TFP.

Motivated by papers in line with Oliner and Sichel (2000) and Stiroh (2002), in order to formally explain which mechanism links current ICT to future TFP, we analyze a 2-sector DSGE model which allows ICT to be the general purpose technology (hereafter GPT) of completely different identification strategy and obtaining qualitatively different results.

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<sup>6</sup>However, as suggested by both Greenwood et al. (2000) and Basu et al. (2010), we are aware that conditioning our identifying restrictions only on the direction of RP does not properly measure for technological changes between sectors. This is the main reason why we never impose the direction of RP as an direct identifying condition.

the whole economy. Both sectoral production functions are fed with three inputs: (i) labor, supplied by households, (ii) hard capital, produced by the final sector, and (iii) ICT capital, produced by the ICT sector. As well-explained by both Basu et al. (2003) and Basu and Fernald (2007), a GPT should be able to enhance accelerations in productivity in sectors that are users of the underlying technology. We then interpret ICT as the GPT of the last 30 years of the U.S. economy assuming that exogenous technological changes in the ICT sector are able to affect economy-wide productivity. In particular, when an ICT technology shock arrives, both sectors accumulate ICT capital since it is easier to produce and cheaper to buy. This ICT capital deepening consequently enhances the productivity of both sectors by means of a spillover. Since the purpose of ICT capital is to improve information sharing, the quality and speed of communication must mainly depend on the diffusion of these technologies among agents. As a simple example, owning a mobile phone enables to contact someone instantaneously if the person you want to reach is endowed with the same technology. As a result, the effectiveness of ICT capital is intrinsically related to its own diffusion. We rationalize this line of thought augmenting the production function of each sector with a spillover effect driven by the diffusion of ICT capital. Consistently with this literature and our empirical results, the accumulation of ICT capital is a slow process and the benefits of an ICT technology shock show up in the production functions of ICT-users with lags.<sup>7</sup>

As a last step, we use both our empirical and theoretical results to estimate the key parameters of the model via impulse-response function matching to an ICT technology shock. The key parameters within this set are (i) the elasticity of productivity to ICT capital diffusion, namely the parameter which governs the spillover effect, and (ii) the standard deviation and (iii) persistence of ICT technology shocks. Results consistently point out a positive spillover effect of ICT capital deepening on TFP suggesting that the assumptions made in the theoretical model are supported by our empirical results. We confirm that ICT is a general-purpose technology which enhance productivity of ICT capital users through a spillover effect related to its own diffusion.

The paper is structured as follows. We present empirical results and main robustness checks in Section 2. We then present and analyze the 2-sector DSGE model in Section 4. We estimate via impulse-response matching key parameters of the model and run a series of related experiment in Section 5. Concluding remarks, caveats and prospective future research are discussed in Section 6.

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<sup>7</sup>Notice that differently to Basu et al. (2003) and Basu and Fernald (2007), we interpret the general-purpose nature of ICT in the spirit of an endogenous growth model.

## 2 Empirics

In this section we present our main empirical set of results. Our attempt is to properly identify technological shocks which are only specific to the ICT sector in a Structural VAR context and analyze their impact on key macroeconomic variables. At the best of our knowledge, there is only another paper that attempts a similar exercise: Jafari Samimi and Roshan (2012). Although also this paper identifies ICT shocks, the authors use Iranian data and both identification strategy and main results are qualitatively different.

## 3 Main Specification

In this section we present our main specification where we impose minimal discipline on the identification strategy. It turns out that those set of results presented here are consistent with different robustness checks. Our first-step specification is the following 6-variable VAR

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$$\begin{pmatrix} TFP_t \\ IT_t \\ GDP_t \\ C_t \\ H_t \\ RP_t \end{pmatrix} = B(L) \begin{pmatrix} TFP_{t-1} \\ IT_{t-1} \\ GDP_{t-1+5|t-1} \\ C_{t-1} \\ H_{t-1} \\ RP_{t-1} \end{pmatrix} + i_t \quad (1)$$

where  $TFP_t$  is the log-level of Fernald total factor productivity,  $H_t$  is the level of total number of hours worked per person,  $MI_{t+5|t}$  is the level of Michigan Index of business confidence over 5 years,  $IT_t$  is the log-level of IT investment,  $GDP_t$  is the log-level of real gross domestic product, and  $C_t$  is the log-level of real consumption. All the variables refer to the U.S. economy.  $B(L)$  is a  $(6 \times 6)$  matrix of lag-operator functions of the same order. In our favorite specification the order of the lag operator functions is two which implies that we regress variables at time  $t$  with their own lagged values at  $t - 1$  and  $t - 2$ . Finally,  $i_t$  is a  $(6 \times 1)$  vector of correlated innovations where  $\Omega = i_t' i_t$ .

In order to derive structural shocks  $s_t$  from innovations  $i_t$  we use a standard Cholesky identification strategy which imposes 15 zero-impact restrictions. Our identification strategy aims to identify a news shock and a IT productivity shock. In particular, we adhere to the following definitions of our shocks of interest. In line with the news shock literature,

a news shock is defined as a signal regarding the future exogenous component of TFP.<sup>8</sup> The IT productivity shock (also IT shock) is by definition an increase in the sector-specific productivity that should lead to a natural increase in the IT level of investment. The reason why we seek to identify also this second shock is because we want to disentangle the rise in IT investment given by an increase in the sector-specific productivity to the rise in IT investment due to future signals on exogenous TFP.

## 4 Model

## 5 Model

## 6 Conclusion

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<sup>8</sup>In much of the news shock literature, this definition is not explicit in terms of *exogenous* TFP, because in the absence of an endogenous TFP mechanism, exogenous TFP and total TFP are by definition the same object. Thus, defining a news shock as the shock that moves TFP over the long horizon implicitly amounts to saying that news move exogenous TFP.

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