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General Purpose Technologies: A survey, a critique and future research directions

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Abstract

Since Bresnahan and Trajitenberg's original 1995 article on 'General Purpose Technology (GPT): Engines of Growth', the concept of GPT has slowly but steadily influenced the literature on business ICT (information and communication technology) adoption. In considering business ICT, within the framework of GPT allows to focus on the externalities in ICT adoption which poses challenges for policy and society as a whole. In the literature, these externality benefits of business ICT have rarely been examined. In this context, the article provides a survey of recently published empirical studies (from 2004 to 2013) citing the original article of Bresnahan and Trajenberg. In using the science citation index and citations derived from Google Scholar, we found 1090 articles fulfilling these criteria; from these articles just 57 studies provided some empirical estimation of the productivity impact of ICT. Our survey indicates if GPT refers to whole range of ICT, this might generate misleading results. In general, our results indicate a shift in the discussion on GPT focusing on business ICT. The literature demonstrates that - with the availability of better data - increasingly a better distinction between infrastructure technologies and applications should be used. While infrastructure technologies are uniformly adopted among small and large enterprises, the adoption of applications is a more complex phenomenon. Although some authors argue that there is a productivity impact of ICT, this impact is mediated by employment, wage and size variables. In particular, the adoption of business ICT within small and medium-sized enterprises (SMEs) has rarely been examined.

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1. Introduction

At the time of recession and technological progress of information and communication technologies (ICTs) seems to have slowed down (Gordon, 2012), it seems necessary to better understand the emergence and the characteristics of ICT as a General Purpose Technology (GPT). GPTs have the potential to affect an entire economy across a variety of applications sectors due to growth in the producing sector (T. Bresnahan & M. Trajtenberg, 1995). Most prominent GPTs include steam engine, electricity; and in recent times, microprocessor, computer, internet, broadband and fiber optics. These technologies have a potential to raise the labor productivity hence productivity at micro, meso and macro level. Just like steam engine had a major impact on productivity growth of UK in 1800s; thereby triggering first industrial revolution, ICT might even have a bigger impact on the productivity growth (Crafts, 2011), leading to a "Third Industrial Revolution" (Schienstock, 2004). However, the knowledge used for developing new digital applications can also be used to disseminate new knowledge in the economic activity which spawns a process of transition towards the so-called "knowledge economy" (Sellens, 2009).

GPTs are mostly conceptualized on the basis of the characteristics: pervasiveness, inherent potential for technical improvements, and innovational complementarities giving rise to increasing returns to scale (T. F. Bresnahan & M. Trajtenberg, 1995). Various forms of ICT possess these characteristics. Our survey provides a framework for the discussion on business ICT (Fichman, 2004; Forman & Goldfarb, 2006), but also complements research on ICT business value (Kohli & Grover, 2008; Melville, Kraemer, & Gurbaxani, 2004). In the survey, we focus on the empirical evidence on business ICT in the GPT tradition. Our results show that large, infrastructure technologies do support GPT hypothesis but that the results differ with respect to ICT applications. From a conceptual point of view, it is necessary to disentangle the different ICT applications and characterize differences between "infrastructure technologies" and "ICT applications" as the external effects of these technologies differ.

There have been some noteworthy reviews appearing in the mid-2000s (Carr, 2003; Fichman, 2004; Forman & Goldfarb, 2006; Melville, et al., 2004; Wade & Hulland, 2004) which in detail covered issues regarding the adoption, ICT valuation and productivity implication. They supported the view that further investment in ICT and complementarity effects are important for the growth of ICT as a GPT.

Table 1 provides an overview about major contributions on business ICT linking to discussion on GPTs. It shows that the debate about the productivity paradox of ICT was soaring during the period prior to our study. After some notable articles considering the issue (Barua, Kriebel, & Mukhopadhyay, 1995; Brynjolfsson & Hitt, 1996; Devaraj & Kohli, 2003), it showed that the ICT-productivity paradox was an artifact of time and measurement (Brynjolfsson & Hitt, 2000; Kohli & Grover, 2008).

……..Table 1 about here……

The research on GPT in general and on ICT, in particular, focuses on two set of problems: First, an adoption decision related to the difference between uncertain benefits and uncertain costs of a new invention (Hall & Khan, 2003); and a second decision with respect to the extent to which new inventions are related to productivity (Brynjolfsson & Saunders, 2010). There is some agreement that both decisions are interrelated, but research has rarely focused on the second one. In this study, we are looking at the shifts in the discussion of taking business ICT over the period from 2004 to 2013. The choice of this period has been with the emergence of a variety of new broadband technologies and applications. In focusing on articles citing the seminal work of Bresnahan and Trajtenberg (1995), we consider empirical studies with a focus on business ICT. This results into a total of 57 articles in the survey. There are various reasons for picking up this sample. In contrast to previous reviews, we focusing not only on macro level studies, but include also meso and micro level studies. As pointed out in a recent survey by Cardona, Kretschmer & Strobel (2013), the empirical evidence with respect to the GPT hypothesis of ICT is mixed and needs further investigation. We complement their work by looking at aspects of ICT like ICT application and ICT infrastructure.

In our paper, we want to focus on the most recent debates going on about ICT; as this era is marked with topical phenomena such as fiber optic and broadband. In contrast to the prevailing view focused on ICT investment at an aggregate level or counting the number of ICT employees (Aral, Brynjolfsson, & Wu, 2012), we concentrate on investment in different types of ICTs as it can have competing performance implications (Aral & Weill, 2007). IN addition, we propose that considering all ICTs as GPT may be misleading as it makes more sense to disentangle different ICT technologies by making a distinction between ICT-production, administration, logistics as well as communication technologies (Ciarli and Rabellotti, 2007). As a result, we put more emphasis on recognizing the ICT at application level which gives us more insights on level of complementarities, coinvestments, coinventions and implications of ICT[2].

With a different focus, measurement issue with respect to business ICT can be tackled i.e., accounting for correct ICT inputs as highlighted by (Cardona, et al., 2013). Furthermore, breaking the ICTs into functional units would enable researchers to address the adoption issues related to SMEs. As mentioned in the literature, SMEs have their specific needs which are totally different from larger firms. In addition, as highlighted by Brynjolfsson & Sauders (2010) ICT does not only reflect productivity but a big part of it is related to intangibles which are hard to measure.

The purpose of this review is to summarize what we know about ICT as general purpose technology, how various themes regarding ICT as GPT have been taken up in the literature and suggesting what we need to know in this vein. The main target is to understand to what extent ICT can be considered as a GPT and what can we learn from the discussion with respect to the growth of GPTs.

[2] There is some ambiguity regarding what constitutes GPT in ICT context. In this paper, we will take up all forms of ICT infrastructures, investment in ICTs and ICTs at the application level keeping the general trend of discussion on this issue intact.

We find that the literature on business ICT in this tradition provides new insights into the relationship between business ICT and performance with respect to the effects of new services (in contrast to infrastructure) applications and their positive performance effects. Studies in our sample cover: 1) the main determinants of ICT adoption/ diffusion, 2) the particular form of digital divide, 3) the impact of adopting ICT, 4) the reasons that ICT has varying returns/ outcomes for different target groups, 5) the relationship between ICT and value creation and, finally 6) the role of ICT in knowledge creation.

The sample consists of studies at country, industry and firm level which consider ICT according to 1) infrastructure (hardware, broadband, and telecommunication equipment) and 2) services (e-business and enterprise software). Our results indicate a shift in the discussion of 'ICT as a GPT' literature around early 2000s where empirical evidences increasingly shows that the traditional way of taking aggregate measures of information capabilities provide an incomplete snapshot of a rather more complex and richer mechanism of productivity and this undermines the ICT potential as 'Enabler of Innovation' and hence the GPT aspect of ICT. Studies highlight a need for looking at particular technologies and their roles to understand the ICT and organizational complementarities. Therefore, empirical studies are increasingly aimed at disentangling ICT infrastructure from ICT business services. Furthermore, a growing evidence of endogenous growth models has been noted where a number of studies underline a skill-biased technical change. In addition, the network aspect of ICT corresponds to endogenous adoption process which is affected by the local industrial structure; different functionalities of various ICTs are found to have distinct diffusion characteristic. ICT has been used for communication leading to the formation of new knowledge by the collaboration which has extensively been discussed. The GPT properties on broadband are only recently being tested but further empirical support is needed to drive the policy agenda.

2. Literature Review

2.1. Literature Synthesis

We systematically searched articles citing Bresnahan and Trajenberg's original article from 1995 using google scholar and the science citation index. As a result, we arrived at 1462 articles citing their article[3]. Second, we filtered according to year of publication and extracted articles from the period 2004 to 2013. This resulted in a sample of 1090 articles. Then, we looked at the articles one by one to whether they are related to business ICT which resulted in a total of 251 articles. From these articles, we looked for articles that were empirical published in the academic journal (discarding the chapters in the books and conference papers). This resulted into 57 articles fulfilling our criteria. The details are listed in Appendix 1.

2.2. A Thematic Analysis of General Purpose Technology Publications

The papers were analyzed and grouped according to their thematic content. Bresnahan & Trajtenberg (1995) state that "GPT's are characterized by pervasiveness, inherent potential for technical improvement and 'innovational complementarities', giving rise to increasing returns to scale" (see Figure 1 for a schematic representation). Block 1 contains pervasiveness, inherent potential for technical improvements and innovational complementarities as major components explaining increasing returns to the scale. Papers in our sample are addressing one or more of the characteristics of GPT as defined as in the left hand side block. In other words, we want to explain how ICT can generate higher returns. From the recent surveys of Cardona et al., (2013) and Draca et al., (2006), we conclude that ICT does indeed contribute to increasing returns to scale but how ICT generates to higher returns has been a grey area which needs further investigation as pointed out by Kohli & Grover (2008). Our focus in this survey is to study in detail the components which determine increasing returns to scale from GPT perspective i.e., the left hand side of Figure 1.

……..Figure 1 about here……

Based on the characteristics of GPTs by Bresnahan and Trajtenberg (1995), we analyze recent empirical studies taking up ICT as GPT on the following dimensions:

1) Pervasiveness ICT is considered as "ICTs pervasive use in all the sectors" or "use of these technologies as inputs by many downstream industries". Although this means that ICT are already diffusing in a wide range of application sectors (Ciarly and Rabellotti, 2013). However, the extent and speed of technology adoption is not ubiquitous and often depends upon the presence of complementary factors (Beaudry, Doms and Lewis; 2010). Further, the process of adoption and practical usage is gradual hence older and

[3] as of August 08, 2013.

newer systems have to work in parallel with each other over longer periods of time. Hence “pervasiveness is the potential broader application of a GPT in a wide range of areas where economic activity is conducted”.

2) Innovation complementarities with respect to ICT is described as the “intensity of R&D in downstream industries increases as a consequence of innovation in the GPT”. This is a very broad concept covering many forms of innovational activities mainly taking place at inter and intra organizational level, categorized into product/ services, process, organizational and marketing innovation (Guerrieri & Padoan, 2007).
3) Inherent potential for technical improvements on the basis of ICT is related to “technological dynamism”, where a technology not only evolves over time, its marginal cost of reproduction is only a fraction of original cost of production, highly customizable and innovated endlessly (Park, Shin and Sanders, 2007).

As it can be seen, if ICT has enabling characteristics (i.e., paving way for further developments and innovation), it can be classified as GPT but this creates implications for policy decisions such as whether, how and when to invest in ICT. ICT as GPT also means that there is an impact on productivity based on two mechanisms: First, this can be due to capital deepening and replacing the less efficient input by the more efficient one (Gordon, 1999, 2000). In this view, no total factor productivity improvements are in other than ICT producing sectors. The second mechanisms stems from the importance of the knowledge economy (Oliner & Sichel, 2000). ICT due to its inherent characteristics of digitization improves firm performance by innovation, restructuring, and more efficient mechanisms. Hence the spillovers generated have an impact on ICT producing as well as ICT application sectors.

In the debate on the business value of ICT, it has been argued that the accessibility of technology hardly related to superior performance (Bharadwaj, 2000; Brynjolfsson & Hitt, 2000; Powell & Dent-Micallef, 1997) because as technology is available to anybody including competitors it cannot provide a strategic edge to a company (Carr, 2003). The GPT characteristic of ICT implies that ICT has the potential to create competitive advantage by being complementary to certain other organizational resources that could make it difficult for competitors to imitate it and to erode the positive competitive effects of ICT (Arvanitis, 2005). These complementary human and business resources result in a non-uniform diffusion of technology through sectors and firms.

Innovation is one important complementary resource of ICT. The literature has identified ICT combined with innovation (called ICT-enabled innovation) has potential to provide superior returns. Various studies identify the reasons why and how companies use ICT. This includes: online ordering, good customer services, increasing switching costs, fast and cheap delivery services, JICT delivery, reducing inventory costs, improved supplier relationship, increasing operational efficiencies, improve services. These primary purposes have not changed over last three decades.

……..Table 2 about here……

Now we will see one by one how present literature addresses each of the three parts of definition.

Research Theme 1: On the Main Determinants of ICT Adoption/ Diffusion

A number of studies (Fabiani, Schivardi, & Trento (2005), Wolff (2006), Ciarli & Rabellotti (2007), Forman, Goldfarb, & Greenstein (2005b), Forman, Goldfarb, & Greenstein (2005a), Forman, Goldfarb, & Greenstein (2005c), Haller & Siedschlag (2011), Tsikriktsis, Lanzolla, & Frohlich (2004), Galliano & Roux (2008)) provide important insights into the understanding of the process of adoption and diffusion of ICT considering ICT as a GPT.

Forman & Goldfarb (2006) in their survey on "ICT Diffusion to Businesses" identified two key dimensions derived from earlier literature. The first dimension is ICT adoption costs (or ICT adoption benefits), second one is internal organization of the firm or the external environment.

The recent literature has pointed at a clear distinction between infrastructure technologies (and applications) and differences within applications. Inter and intra-firm level studies indicate that path of ICT diffusion is uneven across firms, industries, time and space. Forman, Goldfarb and Greenstein, (2005 a,b) are among the studies which closely monitor the adoption process by making distinction between basic communication (email, browsing) so called participation and complex change inductive internet technologies (e-business) so called enhancements. They further classified them into the following categories: within establishment communication (WEI) and cross establishment communication (CEI). As a result, they found varying patterns of adoption in each of these categories. While global village theory is mainly supported in case of participation within which strong support is found for CEI, urban density theory is held up for complex technologies in which strong support is found for WEI. Their study is a major milestone motivating to study adoption based on the "functionality of ICT" rather than treating ICT with holistic approach. However, they do not study patterns of adoption in SMEs. [4]

At the firm level, studies investigate different sets of ICT infrastructure and applications taking both traditional and non-traditional variables leading to ICT adoption. Haller & Siedschlag (2011) provide insights into the adoption of *inter-firm* (usage of website and online orders) and *intra-firm* technologies (share of employees using computers and share of turnover due to online transactions) on rank and epidemic models. Fabiani, et al., (2005) take the case of PC, ICT expenditure, software, website updating and network technologies on firm's internal characteristics, labor flexibility and local industrial variables, Ciarli & Rabellotti (2007) and (Galliano, Roux, & Soulié, 2011) make a distinction between *"generic ICT"* (ADSL) and *"Strategic ICT"* (taking the communication technologies such as active use of website and adoption of E-commerce). Another evidence from *"generic technologies"* comes from Galliano & Roux (2008) which takes the case of adoption and intensity of use of

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email and *internet adoption.* Ulmanis and Denins (2012) also study the adoption patterns of "general ICT" and "ICT uses" (client web processes, business process and enterprise planning applications). In the non-traditional factors, Tsikriktsis, Lanzolla and Frohlich (2004) investigate the antecedents of adoption of *e-processes* (e-CRM and e-transaction) by service firms.

The commonality in all of these adoption studies is their emphasis on the so called *"generic (or infrastructure)"* and *"strategic"* technologies and we can see clear differences in their adoption paths. The studies indicate that the urban-rural divide does not exist for the basic or generic technologies but urban firms are more intensely using technologies (Galliano & Roux, 2008; Galliano, et al., 2011; Haller & Siedschlag, 2011). Further, human capital is a strong factor for determining adoption of these technologies (Fabiani, et al., 2005; Haller & Siedschlag, 2011)

Studies on the intensity of use have found that the adoption of these basic technologies are similar in urban and rural firms while significant differences are noted between the two groups in terms of intensity of usage where urban firms tend to use them more intensely. At the intra-firm level, firm size do not correlate with intensity of use (Galliano & Roux, 2008) and even the pace of diffusion of the new technology seems faster in small firms (Galliano, et al., 2011). For more complex applications such as e-processes, expected performance benefits play a key role in technology adoption(Tsikriktsis, et al., 2004).

On country level diffusion of ICT, Doong and Ho (2012) record that countries with higher gross national income (GNI) tend to invest more in ICT infrastructure and have higher ICT development paths. Further, country and region fixed effect seem to play a role in diffusion of these technologies. Guerriri, Luciani and Meliciani (2011) tested the GPT characteristic of ICT by investigating the decision to invest in these technologies and conclude that the general business environment where the investment is taking place matters for the investment decision. They include facilitating conditions such as changes in the market regulation, amount of human capital, expenditure on R&D and share of dynamic services sector in the economy. It is often stated that slower productivity growth of the countries in the European Union (EU) compared to the United States are attributed to differences in the use of ICT but despite raising the share of ICT in EU countries, the labor productivity growth in most of these countries has slowed down. Biswas & Baptista (2012) conclude that there is a high disparity between small and large firms in EU in terms of using sophisticated ICT. As Brynjolfsson (2000) has shown, ICT does not make the pie of profits bigger but redistribute it so the benefits of ICT accumulates to firms using sophisticate ICT which in this case are the larger size firms. They further raise the concern that due to strict labor law implemented in EU, it is hard to replace a non-technical worker by a worker who has (or has more) superior ICT skills. At the technology level, reduction in the price of substitute technology and/ or increase in the price of substituted method increase the likelihood of technology diffusion (Kumar, Malathy, & Ganesh, 2011).

The studies have indicated that pervasiveness is shaped by market conditions, geographical factors and internal firm features.

Research Theme 2- ICT and Digital Divide

The ITU (2009) has identified three main factors for the digital divide which are related to the difference in access, use or knowledge of ICT. In general terms, the literature on the digital divide has focused on two main areas: the first one has been on measuring the digital divides, extent and pace and, the second area was on explaining the determinants of this divide (Corrocher & Ordanini, 2002). The literature on the digital divide has addressed this phenomenon on a country, regional and firm level. In summarize the key factors of disparities in ICT adoption, Vicente & López (2011) found that differences in economic wealth between countries and individuals are the factor with the highest explanatory power. Besides this factor, disparities are also rooted in educational attainment, population size, density and degree of urbanization.

Studies have examined the country level digital divide in focusing in more detail on the *global digital divide* (the gap between the countries) and *domestic digital divide* (the gap between groups within countries). The cross-country digital divide emerges from social and economic inequalities among developed and developing countries. In the context of GPT, Cuervo and Menezdez (2006) explicitly address this issue by studying the development of ICT across EU-15 countries. Using a composite indicator approach they state that the digital divide takes two forms, the first related to ICT infrastructure and second one related to costs and online public services. Doong and Ho (2012) show in addition that most countries had convergent ICT development path and countries with different levels of GNI have different ICT development path. Countries with higher GNI tend to invest more in ICT infrastructure and investment. They also indicate country and region fixed effects.

Research at the regional level has rarely been undertaken and refers mostly to data generated on the basis of the US broadband map, there are just a few studies focusing on the EU level. Vincente and Lopez (2011) measure and explain the digital divide on regional basis on 164 regions of EU-27 on both measurement and explanation of digital gap. Their results indicate a high digital divide between EU territories and the gap between top and bottom regions exceeds 50 percentage points in all indicators. The income gap does not stop reflecting even after instilment of EU funds for overcoming the gap. Further, skilled workforce and native English speakers are positively correlated with regional ICT scores while regional unemployment rates and older population are negatively correlated while urban-rural gap does not reflect on the ICT scores (Vicente & López, 2011).

At the firm level, the recent literature has indicated that there is a need for addressing the "why" question pertaining to ICT adoption i.e., why firms use ICT at varying rates. Galliano and Roux (2008) use rank and epidemics diffusion models to examine factors related to adoption and intensity of ICT usage. They found that spatial inequalities are no longer significant in the process of ICT adoption but are other components are important in determining ICT appropriation and usage. SMEs are generally considered to adopt less, compared to their larger counterparts, and take longer time to adopt ICT technologies. Benefits expected by small firms are reduced as the need for monitoring is low and the costs inherent to adoption are high. The size of the firm can have ambiguous effect on the intensity of use. The prior literature has been shown that intra-firm diffusion in medium-sized firms is the highest (Hollenstein, 2004). Hence no linear effect of intra-firm diffusion on size and purpose of diffusion changes with respect to size. Larger firms use ICT to better manage informational flows related to their production processes and smaller firms use essentially for

commercial purposes (Greton et al., 2004; Hollenstein, 2004). The studies in our sample indicate that spillover effects do exist in ICT adoption. Furthermore, the presence of larger organizations (Fabiani, et al., 2005; Haller & Siedschlag, 2011) and external pressure (Tsikriktsis, et al., 2004) positively affects ICT adoption.

The literature discusses various forms of ICT to address the digital divide using e.g. broadband technologies (Majumdar, 2008), internet such as email, website, e-commerce (Forman, Goldfarb and Greenstein, 2005b) or other technologies. Forman et al (2005b) argue that advanced Internet usage is shaped by prior distribution of industry In contrast to the current view that economic consequences from Internet exacerbates regional inequalities while benefits are concentrated only in a few locations.

Research Theme 3- Impact of Adopting ICT

This research theme has been broadly discussed in the literature under the heading "business value of ICT". The foundation of GPT is rooted in the idea that diffusion of GPT is associated with superior performance at a country, industry or firm level. In our sample, studies show that the growth contribution of ICT is associated with higher country productivity (Park, Shin, & Sanders, 2007), superior industry level performance (Edquist, 2011) and firm level performance (Aral, et al., 2012; Chang & Gurbaxani, 2012; S. Majumdar, 2010; S. K. Majumdar, Carare, & Chang, 2010; S. K. Majumdar & Chang, 2010). Again, empirical evidences has focused on investment in various ICTs or taking the specific cases of certain infrastructure or application.

Firm level evidence shows that ICT stands out in terms of producing superior performance. Studies show that applications and infrastructure which are widely available throughout the economy (such as web infrastructure) produce no additional benefits to e-business value while that firm's strategies to create competitive advantage (such as internet based innovation) do indeed contribute to e-business value (Soto-Acosta, Loukis, Colomo-Palacios, & Lytras, 2010). Further, studies on broadband adoption indicate that broadband adoption has a positively impact on wage levels but negative association with employment level (S. K. Majumdar, 2008), while positive relationship between broadband deployment and carrier's productivity exist (S. Majumdar, 2010). Another study on US local telecommunication exchanges from 1995 to 2000 period indicate that deploying digital network technology has a positive impact on firms' productivity but is negatively associated with price recovery equation (S. K. Majumdar & Chang, 2010) while broadband deployment is positively related to carrier's productivity (S. K. Majumdar, et al., 2010).

Firm level evidence further points out that the impact of ICT on innovation for example product innovation are positively related to the number of use of communication technologies (websites, e-commerce, intranet) (Ciarli & Rabellotti, 2007). In a study on German firms, Engelstätter indicates on the firm level that SCM systems influence firm's likelihood of potential process innovator, ERP increases number of process innovations, CRM systems increase firm's likelihood to acquire product innovations while firms using SCM experience increase in expected product innovation (Engelstätter, 2012). Furthermore, it has been shown that ICT resources have a direct impact on efficiency in the use of human resources (Fung, 2008). In addition, ICT enables various impacts of innovation (Gago & Rubalcaba, 2007) and e-HRM services are positively associated with organizational innovation in Information and Electronics companies in Taiwan.

At the country level, it has been shown that internet penetration raises real GDP per capita on a sample of 201 countries from 1988 to 2010 (Chu, 2013). Dimelis and Papaioannou demonstrate that a high growth contribution of ICT for 42 developed and developing counties from 1993 to 2001 and a significant ICT effect on growth over a period of 1980 to 2000 in both US and EU (Dimelis & Papaioannou, 2011). Oliner and Sichel show that ICT's have a central role in productivity increases in the United States between 1995 to 2000 but a significant however smaller role after 2000 (Oliner & Sichel, 2000). Country level evidence also suggests that ICT's positive effects on productivity on the country which is importing ICT. This effect is only significant when the exporting country is ICT-intensive or has high-tech industry (Park, et al., 2007).

As recently found by Cardona, et al. (2013), we can confirm a positive correlation of ICT with economic growth. ICT investment is positively linked to and significantly effects economic growth and technical efficiency. Castiglione (2011) and Castiglone and Infante (2013) show that ICT investments together with complementary factors positive affect the total factor productivity (TFP) of Italian firms through direct investments and indirectly through new composition of inputs required by ICT investments to optimize their benefits. Furthermore it has been shown that ICT investment has little association with product innovation but is strongly correlated with technological changes in processes and organizational innovation (Ciarli & Rabellotti, 2007). Using the EU-15 and US data on real output, employment and labor productivity Jiménez-Rodríguez (2012) concludes that increase in ICT investment is positively related to larger growth in real output, employment and labor productivity. The positive impact on labor productivity in ICT-intensive industries is larger after mid-1990s with US being the most positively affected country. Further, it has been shown that ICT goods earn above normal returns in the US (Wilson, 2009)

Research Theme 5- How does ICT create Value?

Figure 1 shows the mechanisms through which a GPT produces increasing returns to scale: The wide acceptability and applicability of a GPT (in other words pervasiveness) implies that application sector of a GPT form the key factors to its increasing returns. However, each sector has its distinct demand due to which the GPT has to dynamically provide applications which cater the specific demands of applications and this dynamism and open field to experimenting within the technology is a distinct character of a GPT. A GPT provides application sectors with the opportunity to generate new processes within the sector which is complemented by the technical progress going on within the GPT and these complementary innovations further increase returns to scale.

Bresnahan & Trajtenberg (1995) address dynamic issues related to GPT. The GPT and its Application Sectors (AS) undergo a bilateral technical progress over time, GPT and AS inability to correctly estimate each other's rate of progress and the "too-little, too-late" innovations which deters the social gains from GPT. So in this section, we are going to have a closer look as to how our sample addresses private returns to adopt new technologies, returns to innovation at firm level and the subsequent returns to scale.

In their paper, Bresnahan & Trajtenberg (1995) emphasize the generic function of a GPT. In this context, ICT is too broad a phenomenon to be associated to a generic function. The papers in our sample include the number of forms of ICTs and their subsequent "generic functionality". We list these types and generic functionalities in the Table A.2. of the

Appendix. It should be noted that all ICT types are not covering the "'how' these technologies generate additional output?" aspect.

…….Table 3. About here……

In infrastructure technologies, broadband is a fairly recent phenomenon within the GPT field. Broadband provides opportunity to access the network for multiple purposes like voice, streaming, emails, online interaction and various media and since broadband enables alternative functionalities and hence complementary technologies can be run on the local loop, therefore the deployment of broadband has positive effect on deploying firm's revenue growth (S. Majumdar, 2010) and wage levels (S. K. Majumdar, 2008). In addition to the simple infrastructure management task provided by copper twisted pair, broadband provides several valuable tasks such as product and process innovation, CRM and repertoire of the activities of telecom companies and these additional tasks help generate new business opportunities hence additional outcome (S. Majumdar, 2010). Because ICT possess capital-skill and technology-skill complementarities (Bartel & Lichtenberg, 1985), and digital network technology are of one the potential technologies to be possessing these complementarities (S. K. Majumdar & Chang, 2010); they add to firms productivity and profitability. Other evidence of broadband-skill complementarities has shown that broadband has a positive impact on productivity in localities with high level of human capital/ highly skilled occupation indicating skill-biased technological change (E. Mack & Faggian, 2013).

Studies on broadband are limited with respect to regional differences caused by broadband growth and the emergence of a digital divide at the country level. Further research has to show how firms utilize broadband to produce complementary innovation.

Similarly, the case of personal computers is also related to enabling technology skill complementarities. Beaudry, et al., (2010) addresses this technology skill complementarities taking the case of the personal computer (PC) stating that such technologies are adopted more intensively in cities where initially the wages are low. The adoption of these technologies finally lead to faster returns rise faster in the more educated markets. Generally, the supply of skills has been considered as negatively related to the returns to skill but during a period of a technological paradigm (skill bias). However, research has shown that this is not always the case and returns to skill can increase where there is more skill supply. Increase in skill leads to a faster diffusion of new technology without decreasing wages. Moreover, endogenous diffusion should not lead to a situation in which returns to skill are highest in localities which have adopted technology more intensely. Furthermore, computer use increases the levels of interactive and numerical skills, workers who use computer at work and possess higher level of interactive skills receive higher wages and computer use complements non-routine tasks which contribute towards wage premium (Dey, Fan, & Peng, 2011). In contrast, Guiri, Torrisi & Zinovyeva (2008) did not find any complementarity between ICT and skills.

Bresnahan, Brynjolfsson & Hitt (2002) note that ICT enables a radical restructuring of work that allocates routine, well-defined tasks associated with symbols processing to computers and separate and redesign tasks that require human skills. Moreover, with ICTs enabling an

individual worker to have all the required information for completing a complex part of a process, the historical fragmentation of many processes can be dramatically reduced resulting in large efficiency gains. Therefore, ICT investment has a direct impact on efficiency gains by reduction in labor costs (Fung, 2008) and on the technical efficiency of firms (Castiglione, 2012; Castiglione & Infante, 2013).

ICTs can have an important impact on value creation because these technologies can lead to superior responsiveness of operating processes and to sound improvements in product offerings (Belvedere, Grando, & Bielli, 2013), influence product, process and organizational innovation (Ciarli & Rabellotti, 2007), while enterprise software systems positively affect product and process innovations (Engelstätter, 2012). ICT and client-provider interaction facilitate different types of service innovations, with ICT and virtual organization affecting organizational innovation (Lin, 2011). Furthermore an e-business strategy leads to adaptation of business processes increasing the level of decentralization at the firm level (Loukis, Soto-Acosta, & Pazalos, 2013).

Spillovers constitute an important research area. At the firm level, Chang & Gurbaxani (2012) measure spillovers on firm level productivity improvements over a long term horizon. They conclude that spillovers are high and significant but their magnitude and persistence vary. In addition, ICT related spillovers do not persist in low-ICT intensive firms. At the industry level, Han, et al., (2011) show that industries receive significant ICT spillovers in terms of TFP growth through economic transactions with their respective suppliers. ICT intensity and competitiveness play an important role in ICT spillovers. At the country level, Gholami, et al., (2009) state that due to ICT involving traditional as well as knowledge capital, spillovers can occur through various mechanisms. They find that developing countries can reap more benefits from ICT spillovers than developed countries. Further, internet penetration in the recipient country also implies ICT spillovers. Park, et al., (2007) also look at the country level ICT spillovers and find a positive effect of foreign ICT transfer on the recipient country's productivity. They also find that the effect of transferred ICT is only significant when the source country is an ICT-intensive or high-tech export country.

Finally, ICTs can have varying effects in different settings. Aral, et al., (2012) take the case of HCM and finds out that HCM adoption is associated with a large productivity premium when it is implemented as a system of organizational incentives, but has less benefits when adopted in isolation. The system of three-way complements produces disproportionately greater benefits compared to pairwise interactions, highlighting the importance of including all three complements. Further, it is necessary to understand that investment in ICT fixed capital is necessary but not sufficient condition leading to productivity gains. The effective implementation of ICT requires changing economic structure characterized by a growing weight of service sectors and complementary investments in ICT services. The effective implementation of ICT indeed requires on the one hand a changing economic structure characterized by a growing weight of service sectors and on the other hand complementary investments in ICT services, directed to ease the integration of the new technologies within firms' boundaries (Quatraro, 2011). Melville et al., (2007) find that marginal product of ICT is higher in more dynamic industries and this underscores the salience of inclusion of competitive environment in studies of ICT value creation.

Research Theme 6- ICT and Knowledge Economy

This research regime emphasizes that ICT, ICT related activity and ICT-workers are distinguished from regular capital and they have above normal rate of returns. In this regard, Le Bas & Miribel (2005) show that geographic concentration of ICT employment has a greater positive effect on labor productivity than the geographic concentration of all other activities, and this refutes the so called “death of distance” argument. As for specific form of technology such as broadband, Mack (2012) finds that in some localities, broadband appears to be essential link that enables knowledge firms to strategically locate in lower cost counties while in other cases, broadband is unable to counter the negative externalities associated with remote area localities. Further, Mack & Faggian (2013) find that broadband has positive impact on productivity only in localities with high levels of human capital and/ or highly skilled occupations. With the rise of ICT, the number of information workers has also increased over the period of 1950 to 2000 (Wolff, 2006) for which the main determinants turn out to be R&D expenditure and computer investments.

Summary and conclusions

In this paper, we examined the empirical literature citing the seminal work of Bresnahan and Trajtenberg (1995) on ‘General Purpose Technology (GPT): Engines of Growth’ over the period 2004 to 2013. We found prior to 2004 a general consensus about some stylized facts in the literature with respect to GPT features of ICT. These stylized facts include: 1) the national context influencing ICT adoption as well as use and innovation; 2) larger firms in general adopt ICT and innovate more on the basis of ICT, 3) there are complementarities between ICT investment and organizational co-investment and 4) ICT does create value for companies.

Since 2004, studies in the area of ICT adoption have increasingly used the GPT framework to place the research in a broader economic context. Our research showed that the concept has not only been used extensively but has generated new insights on a variety of aspects of ICT adoption. Based on a GPT framework, ICT adoption is not anymore considered as a phenomenon limited to single firm ICT adoption but the linkages between the adopting firm and its external environment are becoming increasingly important. Secondly, the distinction between GPT producing and GPT application sectors has been very fruitful in the case of ICT adoption. After research on ICT adoption seems to have established that the GPT producing sectors (such as telecommunication manufacturing) are at the leading edge of ICT adoption, the focus over the past years has shifted towards the ICT application sectors. In the latter sectors, the results of ICT adoption are not so clear cut and wide variety of differences persists across sectors. Here research on business ICT has provided new insights with respect to size and sectoral differences with respect to ICT adoption. Furthermore, the regional dimension has added new alleys of research on ICT adoption and regional differences.

Interestingly, over the past years the discussion of ICT as a GPT has undergone a shift from differentiating between the various parts of ICT, mainly infrastructure and services. The original concept by Bresnahan and Trajtenberg (1995) to examine, in more depth, the linkages between GPT producing and GPT application sectors as well as between GPT application sectors still is very fruitful to generate new research ideas and put them into the broader context of radical economic changes affecting the society as whole. As we found limited empirical evidence on direct links between ICT infrastructure and ICT service adoption, more research is needed to disentangle the dynamics of these two complementary technologies in the process of ICT adoption and use.

In addition, our paper shows that researchers have taken a variety of perspectives in studying ICT adoption by looking at the broader economic effects of this technology. There has been a wide range of studies focusing on ICT adoption, value creation aspect of ICT, role of SMEs in economic growth and the value creation potential of ICT from a managerial as well as an economic perspective. Studies on the adoption of ICT underscore that size in itself is not sufficient to explain adoption. As prices of ICT assets are decreasing and new technologies are emerging (like cloud computing), it seems that the digital divide based on pure infrastructure technologies is shrinking. This has also serious consequences with respect to studying ICT adoption as a dynamic process involving sectoral, company internal characteristics as well as strategic considerations.

In approaching the adoption of ICT from strategic lens as highlighted by Fichman (2004) and Sadowski et al (2003) enables the researcher to focus more on the new strategic opportunities generated by ICT. In other words, the "technology strategic perspective" can lead to new insights in the process of ICT adoption, in particular, in explaining the opportunities generated by new ICT applications in the area of e-business and e-commerce.

In addition, it becomes increasingly important to examine the linkages aspect of ICT (the functionality perspective). As SMEs pursue lesser linkages with other firms through strategic partnerships, joint ventures and strategic alliances, they are adopting also more basic technology (Forman et al., 2005) and not advanced collaborative technologies. However, it is important to note that technological collaboration is more critical for SMEs than large firms (Nieto and Santamaría, 2010). Studies on the strategic linkages between SMEs and their external collaborators, suppliers, etc. using ICT have rather been scarce. However, these linkages explain how a critical mass of small ICT business users develops that extensively uses advanced ICT applications and combines it with an advanced (e.g. broadband) ICT infrastructure.

As identified by Bresnahan and Trajtenberg, the process of new technology creation is surrounded by high amount of uncertainty and asymmetric information. Policy makers have the opportunity to intervene in ICT markets to reduce uncertainty and provide better information. This might can lead to increased linkages between ICT adopting firms from GPT producing (like telecommunication services) and GPT application sectors (like health sector) as well as between GPT application sectors (like education and health sector). However, currently, less is known about the linkages between these sectors and the way business ICT users can benefit from collaborating with each other across sectors.

Our results have some implications with respect to defining ICT is a "general purpose technology". As we propose that – based on the empirical evidence presented - ICT should be considered as a GPT, further distinctions are necessary to explain differences between infrastructure and applications/services which might have different dynamics in their adoption patterns. In other words, not all "ICT's" can be considered as GPT.

As Bresnahan and Trajtenberg (1995) original article is focusing on the microprocessor as the most prominent technology at that time (other technologies included also electricity, the steam engine), the emergence of research on ICT diffusion has also provided new insights with respect to examining GPTs in more general. For a more general framework on GPT it will become important to look at the extent to which these technologies provide new strategic opportunities for the different market players and their effects on the external linkages of firms. In the original formulation, Bresnahan and Trajtenberg examine these effects based on cost-profitability considerations of the different firms involved, but co-innovation and co-adoption issue (Adner, 2012) increasingly affect the strategic considerations of firms. In addition, as size differences between firms will continue to persist, the industry structure of the application sector becomes an important variable in explaining GPT growth.

Table 1: Overview of prominent previous literature reviews on ICT contributions (in the Early 2000's)

Study	Method	Results
Melville et al., 2004	Develop a model of ICT business value based on resource based view	Investments in ICT provide value but this value depends upon complementary resources, competitive environment, general macroeconomic atmosphere, Synergies between technical and human ICT resources yield short term competitive advantage.
Wade and Hulland, 2004	Explore and critically evaluate the use of RBV of the firm by IS-researchers.	Providing a review of resource based view, typology of IS- resources and then determining resource complementarities and moderating factors for evaluating IS-resource/ firm performance relationship
Fichman, 2004	Using concept from real options to evaluate the investment opportunities in ICT-platforms	Determining the option value associated with investments in innovative ICT platforms to address when a firm should take a lead role in innovation with emerging technologies?
Forman and Goldfarb, 2006	Studying the factors of ICT Diffusion to businesses	Categorized the research into two main themes, adoption costs and benefits, and internal organization of the firm and external environment
Carr, 2003	Comparison with earlier GPTs like Electricity and Railroads	Studying the evolution of ICT, ICT is found out to follow the pattern of earlier GPTs. Its power and ubiquitness has grown so strategic importance is diminished. This makes infrastructural technology which is necessary but not the only condition to attain sustained competitive advantage.

Figure 1: General Purpose Technologies: Important Concepts and Determinants

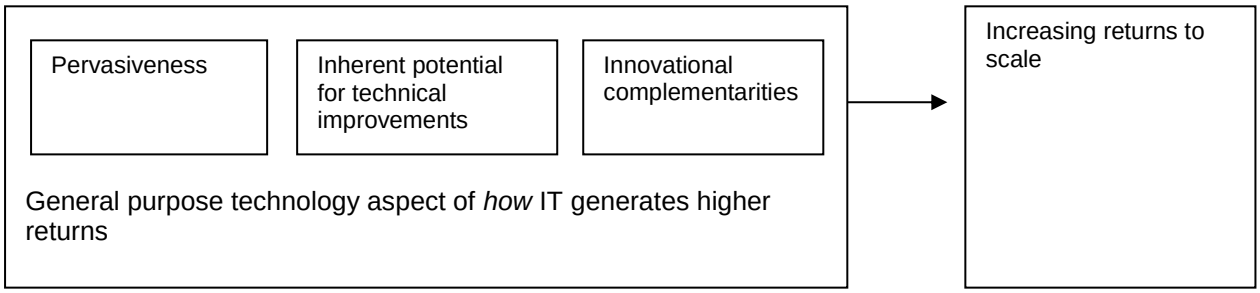

Table 2: Articles Citing Bresnahan and Trajtenberg, 1995 taking ICT as GPT

No	Journals	Articles citing Bresnahan and Traijtenberg (1995)
	ACM Transaction Management Information Systems	1
	African Journal of Business Management	1
	Annual Regional Science	1
	Applied Economics	3
	Computer and Information Science	1
	Decision Support System	1
	Ecological Economics	1
	Economic Systems Research	1
	Economics of Innovation and New technology	3
	Electronic Commerce Research and Applications	2
	Environment and Planning	1
	European Journal of Development Research	1
	European Urban and Regional studies	1
	Industrial and Corporate Change	4
	IEEE Transaction on engineering management	1
	Industry and Innovation	1
	Information and Management	1
	information communication technologies	1
	Information Economics and Policy	1
	Information Systems Research	2
	Innovation and New Technology	1
	International Journal of Human Resource Management	1
	International Journal of Production Research	1
	International Journal of Trade and Global Markets	1
	International Regional Science Review	1
	JAIS	1
	Journal of Business and Economic Statistics	1
	Journal of Economic Studies	1
	Journal of Evolutionary Economics	1
	Journal of management information systems	1
	Journal of Policy Modeling	1
	Journal of Political Economy	1
	Journal of Urban Economics	1
	Management Science	1
	Modern Economy	1
	Operations Research International Journal	1
	Production and Operations Management	2
	Regional Science	1
	Review of Income and Wealth	1
	Scandanavian Economic History Review	1
	Social and Behavioral Science	1
	Strategic Information Systems	1
	Structural Change and Economics Dynamics	1
	Technology in Society	1
	Telecommunication Policy	2
	Total	57

Table 3: ICT Types and their Generic Functionalities According to the GPT

ICT Type	Studies	Generic Function
Broadband	(Biswas & Baptista, 2012; E. Mack & Faggian, 2013; E. A. Mack, 2012; S. Majumdar, 2010; S. K. Majumdar, 2008; S. K. Majumdar, et al., 2010; Prieger, 2013; Vicente & López, 2011)	A transmission medium with wide bandwidth and with its ability to transport multiple signals and traffic type simultaneously. A broadband transforms the composition of local loop network operated by telecom companies.
ADSL	(Ciarli & Rabellotti, 2007)	A data communication technology providing faster data transmission over copper telephone lines.
Digital	(S. K. Majumdar & Chang, 2010)	A technology providing internet access by transmitting digital data over the wires of a telephone lines.
Computer/ PC	(Beaudry, et al., 2010; Biswas & Baptista, 2012; Dey, et al., 2011; Haller & Siedschlag, 2011; Vicente & López, 2011); Dey, Fan & Peng, 2011; Fabiani, Schivardi & Trento, 2005	A technology that can be programmed to carry out set of arithmetic and logical instruction
Internet	(Biswas & Baptista, 2012; Doong & Ho, 2012; Forman, et al., 2005a, 2005b, 2005c; Galliano & Roux, 2008; Galliano, et al., 2011; Gholami, et al., 2009; S. Chu, 2013; Soto-Acosta, et al., 2010; Vicente & López, 2011)	A global system of interconnected computer networks using the standard TCP/IP to provide worldwide services carrying extensive range of information resources and services such as world wide web, infrastructure for supporting emails and peer-to-peer networks
Email	Galliano & Roux, 2007; Galliano, Roux & Soulie, 2010	A technology to support exchange of digital from one author to one or more recipient.
Applications	**Web infrastructure** (Ciarli & Rabellotti, 2007; Fabiani, et al., 2005; Haller & Siedschlag, 2011; Soto-Acosta, et al., 2010; Vicente & López, 2011) **E-Commerce** (Ciarli & Rabellotti, 2007; Fabiani, et al., 2005; Haller & Siedschlag, 2011; Tsikriktsis, et al., 2004) **E-Business** (Engelstätter, 2012; Fabiani, et al., 2005; Loukis, et al., 2013; Tsikriktsis, et al., 2004; Ulmanis & Deniņš, 2012; Vicente & López, 2011) **E-HRM** (Aral, et al., 2012; Lin, 2011) **ATM Technology** (Kumar, et al., 2011)	A service providing shared self-service web content and application hosting environment, discrete web hosting environment, providing web proxy and redirection services. Commercial transaction conducted electronically This includes e-commerce but also covers internal processes such as production, improvements in efficiency, inventory management etc. An IT application for both networking and supporting at least two individuals or collective actors in their shared performance of HR. Electronic outlet which allow customers to perform basic transactions

Appendix 1: GPT Characteristics and performance implications

GPT Characteristics	Classification of Broader Conception	Studies	Key Outcome?	Contribution
Pervasiveness	Skill biased technical change/ complementary role of skill.	Beaudry, Doms and Lewis; 2010	Return to skill	Take a sample of 217 US Metropolitan areas in the period 1980-2000. Results show that higher skill is associated with extra PC adoption; PC is adopted more intensively in cities where initially the wages are low; and finally returns rose significantly faster in the more educated markets. Generally, the supply of skill is negatively correlated with returns to skill but during a period of technological paradigm that is skill bias, this is not the case and returns to skill increase where the skill supply is more. Increase in skill leads to faster diffusion of new technology without decreasing wages. Moreover, endogenous diffusion should not lead to a situation in which returns to skill are highest in localities which have adopted technology more intensely.
		Fabiani, Schivardi and Trento, 2005 (Both study **complementary role** of skills in providing wage returns, as for neoclassic economic model, the role of factors are exogenous but a complementary role of skills provide evidence to endogenous growth model)	ICT adoption	Survey using 1475 manufacturing firms of in the year 2001. Human capital (measured by years of education) is an important indicator of ICT adoption (infrastructure + network technologies)
		Mack and Faggian, 2013 Complementarity	Productivity	Using data for broadband provision of 1999 on productivity changes, from 2000 to 2007 for 3046 counties in US, the results suggest that broadband has a positive impact on productivity in locales with high level of human capital/ highly skilled occupation indicating skill-biased technological change.
		Ciarli and Rabellotti, 2007	ICT investment, Adoption and Use	Survey conducted in 2001 to 92 firms having a T/O higher than 5 million in 1998. Another survey was conducted in 2002 of 50 firms, and when matching firms are dropped, resulting a merge sample of 122 firms. Large size firms, skilled human resource and PC skilled employs are

				important determinant of ICT investment, adoption and use. Skilled ICT entails differences considering various functions such as involving production, logistics, administration and communication. Further, different innovation types such as product, process, and organizational innovation are influenced by different variables.
	786	Mack & Grubesic, 2012 (pervasiveness)	Employment, Earnings, Earning per worker and establishments.	Data on 48 contiguous states from three resources, Regional Economics Information Systems, County Business Partners and Geospatial and Statistical Data from 1977 to 2007. In addition to job creation, industries in which jobs are created and associated wages should also be included. This is because productivity gains associated with ICT is somewhat irregular. Regions with more productive workers and higher aggregate earnings imply that all jobs are not created equal so employment growth as indicator of regional performance does not provide meaningful insights. Thus, use of univariate indicators such as employment growth provide incomplete snapshot of a richer and complex mechanism of regional growth. Hence multivariate benchmarking practices should become norm with would account for time, space and industry.
	IT localization on Productivity	Bas & Miribel (2005)	State labor productivity, County labor productivity,	The study takes 50 US states and the district of Columbia (containing 3,141 county equivalents) for the year 1990. The results provide evidence of positive effects of IT employment on labor productivity, localized diseconomies with non-IT employment and strong agglomeration economies are associated with IT employment location quotient.
	ICT Diffusion	Biswas & Baptista, 2012	ICT use by enterprises	Eurostat data from 2002-2009 on percentages of enterprises using computer, internet and broadband. Despite micro level studies in Europe pronouncing positive impacts of ICT towards economic performance, the macro level studies continue to refute this. The study finds out that small, mini and micro enterprises that are the basic foundation of these economies should be given due and effective attention so that they can install latest high technology like ICT and train their workers to use the technology. A broad based approach, possibly in the form of technology mission, to modernisation of the vast number of enterprises through installing latest information and communication technology and skill up gradation of numerous workers is required. Only then one can expect economy-wide productivity growth

		Wolff, 2006	Rise in knowledge workers (Skill-biased technological change)	Using the data from decennial US censuses of 1950, 1960, 1970, 1980, 1990, and 2000, matrices of employment have been constructed by 267 occupations and 64 industries and then have been categorized into: knowledge producers, data producers, service workers and goods-processing workers. Results indicate steady increase in information workers, and this is due to substitution of information workers for goods and services workers and unbalanced growth effects and not through substitution of information-intensive products. R&D expenditures and computer investments are positively associated with rise in knowledge workers but negatively with data-workers.
	Scale-bias	Majumdar, 2008	Employment, Compensation	Using balanced panel of annual data for US local exchange companies from the Statistics of Communications Common Carriers (SCCC) for the14-yearperiod 1988–2001. Results indicate that Broadband diffusion within and between the firms over time has a positive impact on wage level but negative impact on employment due to scale effect.
	Technology Skill complementarity	Majumdar and Chang, 2010	Profitability, Productivity, Price Recovery	Data for analysis was taken from various sources such as FCC, SCCC, NRRI and US Census Bureau from 1995 to 2000 on deployment of technology and productivity for major firms in the local exchange sector of telecom industry in US. The results show that deployed digital network technology is positively related to firms' productivity and negatively to firms' price recovery. Thus it is beneficial to join digital bandwagon.
	Adoption	Majumdar, Carare and Chang, 2009	Deploying firm profitability	Using data on US telecommunication industry from 1995 to 2000, the authors find positive relationship between broadband deployment and productivity. Broadband deployment create potential for technological efficiencies, and since these firms operate in two-sided market, the benefits from multitude of connections can be substantial because of possible second order spillover effects.

	Networks	Galliano, Roux and Soulié, 2011	Internet Intensity of use	
	Digital Divide	Cuervo & Menendez, 2006	Digital Divide in EU	The multiple dimension of digital divide can be summarized into: the first is related to ICT infrastructure and use and the second to costs and the availability of online public services. Also, digital disparities mirror (to some important extent) social and economic imbalances across countries.
	Digital Divide	Doong & Hu, 2012	GNI	Secondary data on 136 countries from 2000 to 2008 is used where the results indicate Cross country investment on infrastructure depends upon GNI of the country, higher the GNI, greater the telecom investment and ICT development paths.
		Chang and Gurbaxani, 2012	Long run productivity	Using Compustat and Computer Intelligence InfoCorp, covering the sample period from 1987 to 1995 getting a total of 3,088 observations from 386 firms over 8 years. The results show that spillover impacts are highly significant, but that the magnitude and persistence of the impacts vary. Firms with high IT intensity receive greater spillover benefits from the IT services industry. Moreover, these benefits are sustained over a long-term horizon. However, the impact of IT-related spillovers does not persist in low IT intensity firms regardless of the source. Overall, the results shed light on the existence and sources of IT-related spillovers and on their important role in shaping the long-run returns to IT investment. These results also help explain the findings of excess returns to IT investment in the IT productivity literature.
		Galliano and Roux, 2007	Internet adoption	
		Gholami, Guo, Higón and Lee, 2009	ICT diffusion	
		Haller and Siedschlag, 2010	Inter and Intrafirm diffusion of ICT	The paper analyzes factors driving inter- and intra-firm diffusion of ICT using data from Irish manufacturing firms over the period 2001 to 2004. The results show that the path of ICT diffusion has been uneven across firms, industries and space, which is consistent with the theory of new technology adoption. The results suggest that firms that are larger, younger, fast growing, skill-intensive, export intensive and firms located in the capital city region have been relatively more successful in adopting and

				using ICT. We find positive technology spillovers from firms that have adopted ICT located in the same industry and region..
		Han, Chang, Hahn, 2011	TFP	The study is on the interindustry IT spillover wherein IT investments made by supplier industries increase the productivity of downstream industries. Using data from U.S. manufacturing industries, the authors find that industriesreceive significant IT spillover benefits in terms of total factor productivity growth through economic transactions with their respective supplier industries. More importantly, two characteristics of downstream industries are found, namely, IT intensity and competitiveness, which have been shown to moderate the effect of internal IT investments, play an important role in IT spillovers as well. The results suggest that IT intensity as well as competitiveness of the downstream industry moderate the effect of IT spillovers—industries that are more IT intensive and more competitive benefit more from IT spillovers. Finally, the results suggest that the long-term effects of spillovers are greater than short-term effects, suggesting that learning periods are required to reap the benefits from the IT spillovers.
	Micro level aspects	Fabiani, Schivardi and Trento, 2005 (size and organizational changes)	ICT Adoption	Data on 86,879 establishments. Participation reduces Cross Establishment Internet (CEI) costs hence supports global village theory. Adoption of complex enhancements supports global village hypothesis and is driven by Within Establishment Internet (WEI)
	Location (Urban/ Rural)	Forman, Goldfarb, Greenstein 2005b	Internet Adoption	Harte Hanks data using data on 86,879 from establishments that have over 100 employees for year 2000. Participation (simple access to email and web browsing) is substitute to urban agglomeration. Enhancements, (complex application) were complements to urban agglomeration. Role of location was secondary

				to that of industry in diffusion of participation and enhancement. Many areas are meaningful substitute of each other in using complex apps.
		Prieger, 2013	Broadband Adoption	Empirical estimations of broadband provision and usage in the US show that rural areas have fewer high-speed fixed and mobile providers but more slower-speed fixed providers than urban areas. While rural avail- ability of mobile broadband is lower than in urban areas, it still helps fill in gaps in fixed broadband coverage in rural areas. The rural gap in fixed broadband usage remains, but the mobile broadband usage gap disappears after controlling for household demo- graphics. The raw broadband usage gaps between rural and urban households are proportionally greater for low-income households. The potential for mobile broadband to benefit rural areas through economic development is also examined
	Broadband employment	Mack, 2012	Firm location	In an attempt to find out the relationship between spatial distribution of broadband providers and presence of KI firms in US counties, the study utilizes data between 1999-2004, firm level data and broadband data from FCC on providers with 250 or more lines. The results highlight that in some cases, broadband result in knowledge firms strategically locating in low cost counties and in others, broadband is unable to counter the negative externalities related to remote areas.
	Location size	Forman, Goldfarb, Greenstein 2005c	Internet Adoption	Again data on 86,879 establishments of over 100 employees for year 2000. Both industry and location play a significant role in explaining geographic variation of adoption. IT-using is more sensitive to costs/benefits affiliated with location size than IT-producing. Industries with high labor costs and geographically concentrated are more sensitive to changes in gross benefits that occur with increases in location size. So there is an “Industrial Digital Divide”

	Internet penetration	Chu, 2013	GDP	Data is from World bank in a panel of 201 countries from 1988 to 2010. Results show that internet penetration increases GDP per capita, and the significance remain even during recession so internet can be thought of as one of the means to combat economic recession.
	Industry features	Forman, Goldfarb, Greenstein 2005a Galliani, Roux and Soulié, 2011	Internet Adoption Determinants of ICT adoption.	 French national statistical institution data, including all industrial firms with at least 20 employees for 2001 and second dataset on ICT and E-commerce for 2002 and the research obtain typologies as urban, preurban and rural. Results imply that spatial inequalities do not affect adoption but do affect intensity of use. Adoption is affected by level of remuneration, belonging to a group, openness to international markets, level of adoption in the same sector, and negatively by multi unit spatial organization. Intensity of use is affected by remuneration, belonging to a group, level of competition, openness to international market, adoption in local environment, adoption in same sector, level of investment in local environment, high connection speed while negatively by located in rural and industrial agglomeration economies.
	Geographical concentration	Galliano and Roux, 2007	ICT intensity of use	Data drawn from French National Survey of 5,200 industrial firms on “ICT and E-commerce”. Spatial inequalities do not affect adoption but do affect intensity of use. Adoption is affected by level of remuneration, belonging to a group, openness to international markets, level of adoption in the same sector, and negatively by multi unit spatial organization. Intensity of use is affected by remuneration, belonging to a group, level of competition, openness to international market, adoption in local environment, adoption in same sector, level of investment in local environment, high connection speed while negatively by located in rural and industrial agglomeration economies.

	Knowledge transfer	Park, Shin and Sanders, 2007	Productivity growth	The annual time-series data were collected for 39 developing and developed economies from 1992 to 2000. When IT products are traded across borders, IT investment in an economy has a positive influence on the productivity of its import partner country. Empirical evidence is provided for the positive effect of global IT diffusion on productivity through international trading of IT products. The results show a positive effect of foreign IT transfer on the recipient country's productivity. In addition, the effect of transferred IT is only significant when the source country is an IT-intensive or hi-tech export country. The results and implications are robust, even controlling for other important factors such as openness, innovative capacity, and IT infrastructure in addition to the transferred IT. Finally, a panel cointegration test—a recently developed advanced econometric method—is used to address the common problems of spurious relations that arise in regressions with nonstationary time-series data.
	Substitutability with older technology	Kumar, Malathy and Ganesh, 2010	Diffusion of technology	Utilizing data on the diffusion of ATM from 1989 to 2006 in India. Results provide evidence that degree of substitutability of teller with ATM is high but ATM is not perfect substitute
	Macro level aspects (general market conditions such as market regulations, amount of human capital, share of dynamic services sectors)	Guerrieri, Luciani, Meliciani, 2011	Investment in ICT	The authors assess the determinants of information and communication technology (ICT) investment at the macro-level, for a panel of 10 advanced countries, in the period 1992–2005. We investigate the idea that, since ICTs are general purpose technologies, the decision to invest in these technologies is strongly affected by the general business environment in which the investment takes place. The empirical results are consistent with this idea: facilitating factors such as changes in market regulation, amount of human capital, expenditure on R&D, and the share of the dynamic services sector in the economy, positively influence investment in ICT.
	Rational efficiency, bandwagon effects	Tsikriktsis, Lanzolla, and Frohlich, 2004	Adoption of e-processes	Study based on 338 services firms in UK and investigates empirically antecedents of the adoption of web-based processes (e-processes) by service providers. The authors examine whether rational efficiency (expressed by expected performance benefits and access to new markets), the bandwagon effect (expressed by external pressure), and barriers (both internal and customer related) influence Internet use for transactions (e-transactions) and/or to extend the relationships between service providers and their customers (e-CRM). The

				authors show that rational efficiency and the bandwagon effect drive both types of e-processes. Conversely, only internal barriers have a negative impact on adoption of e-processes, while barriers related to customers do not have a significant impact. These findings have important academic and managerial implications, given the limited evidence regarding the implementation of e-processes in services.
	Regional policy, income gap	Vicente and Lopez, 2011	Digital divide	Eurostat data for years 2006-2008. The paper attempts to measure the digital divide across the regions of the 27 Member States and within each country and explain the observed regional disparities. The analysis leads to identify Dutch regions as the Top-10 in ICT, while Greece and Bulgaria occupy the Bottom-10. Therefore, results show that the regional digital divide reflects to some extent the income gap. However, regional policy seems to be having some positive implications for technology adoption. In particular, the rural-versus-urban dimension of the digital gap appears to be less important than it is usually claimed to. Likewise, some evidence is found of the role of cultural and institutional factors in ICT adoption, an issue that has not been previously analyzed at the regional level.
Innovation Complementarities	Complementarities of Skill with computer usage	Dey, Fan and Peng, 2011 (skill and non-routine task)	Computer use, computer use wage premium.	Use employee wage, computer use, skill set and job requirements data for 12,000 occupations using panel for 2000-2001. Results indicate that the use of computer is positively and significantly related to both interactive and numerical skills. Computer use and interactive skills increases logwage while computer use and numerical skills do not. In essence, the study finds out that computer use is related to increase in need for skilled and educated labor. A complementary work practice including hiring educated employees is complementary. Also computer use is complementary to non-routine tasks especially abstract tasks in explaining wage returns (Innovations and co-inventions)

	Product, Process, Organizational innovation	Gago and Rubalcaba, 2007	ICT and innovation interaction	Madrid Survey on Innovation between 2002-2003 of 557 enterprises, Specific impacts of innovation are examined by carrying out an ordered probit model with sample selection. Results indicate a certain correspondence between the multidimensional nature of service innovation and a preliminary impact assessment. The paper notes that ICT and clients–providers interactions are both important, acting to facilitate different types of service innovation.
	Internet based innovation	Acosta et al., 2010	E-business value	Using European e-business Market Watch data which result in getting a total 1,010 total firms, the result show that Internet based innovation significantly and positively affects e-business value. On the other hand, web infrastructure does not correlate with e-business value (measured by e-sales effectiveness), and also there exist no complementarities between internet based innovation and web-infrastructure in getting higher e-business value.
	Product and Process	Belvedere, Grando and Bielli, 2012	Value creation (measured by 1-Investment in ICT create economic value for the company, 2- Integration between information systems and communication technologies creates economic value for the company).	In an attempt to measure the impact of ICT on Product offering and operating processes to look at IT's effect on value creation, the study conducts a survey which result in a total no. of 109 usable responses located in Italy. The results show that ICT has an impact on value creation through both product offering and operating processes improvement.
	ERP, SCM and CRM	Engelstätter, 2011	Product and Process innovation	Using data from Center for European Economic Research from 2004-2007, where each wave of this data contains information about 4000 service and manufacturing firms in Germany. Result reveal that SCM increases likelihood of becoming process innovator, ERP increases number of process innovation, CRM increases firms likelihood to acquire product innovation, number of expected product innovation increases with SCM.
	IT& Process innovation	Fung, 2008	Stochastic labor requirement function	Data on top 100 Bank Holding Companies from 1992 to 2003 getting a final sample of 79 BHCs. Both categories of labor saving technology have a positive impact on efficient use of human resource. IT has a direct, while in-house process innovation have an indirect effect through knowledge spillover.

	ICT, Skill and Organizational Change	Guiri et al., 2008	Value added	Evidence from SMEs, of a panel of 680 Italian manufacturing firms from 1995-2003 to find complementarities between ICT, skills and organizational change. In case of SMEs, the authors find complementarities between ICT and OC but not between ICT and Skills. Full complementarity between ICT, OC and human capital does not apply to SMEs. OC yields negative effects on human capital and ICT
	IT, HR analytics and performance pay	Aral, Brynjolfsson and Wu, 2012	Productivity	Using data on 189 firms for 11 years. Results indicate adoption of HCM software is greatest in firms that have also adopted performance pay and HR analytics practices. Furthermore, HCM adoption is associated with a large productivity premium when it is implemented as a system of organizational incentives, but has less benefit when adopted in isolation. The system of three-way complements produces disproportionately greater benefits than pairwise interactions, highlighting the importance of including all three complements. Productivity increases significantly when the HCM systems "go live" but not when they are purchased, which can be years earlier. This helps rule out reverse causality as an explanation for our findings.
	IT (hardware) and investment in IT services	Quatraro, 2011	Productivity	Evidence from Italian services and manufacturing firms indicate that neither ICTs capital nor services are properly diffused across the traditional manufacturing sectors, while knowledge-intensive sectors are characterized by a marked adoption of ICT capital, but very low levels of services procurement. The econometric results accordingly show that capital and services are complementary rather than substitutes. The complementarity between ICT capital and services makes the latter indispensable in order to feed ICT-driven economic growth. Firms operating in traditional manufacturing sectors are indeed unlikely to command the set of capabilities that are necessary to make the hardware apparatus work effectively.
Inherent potential for technical improvements	Close to core of GPT Technological capability Intensity of ICT usage	Castellacci, 2010	Productivity performance Industrial growth	Investigates the empirical relevance of a model of structural change and the growth of industrial sectors. The model analyzes the process of diffusion of GPTs and how this affects the dynamic performance of manufacturing and service industries. The empirical analysis studies the dynamics and the determinants of labor productivity growth for a large number of sectors in

				18 OECD countries over the period 1970–2005. The results of dynamic panel data and cross-sectional analysis provide support for the empirical validity of the model. Industries that are close to the core of ICT-related GPTs are characterized by greater innovative capabilities and have recently experienced a more dynamic performance. Relatedly, countries that have been able to shift their industrial structure toward these high-opportunity manufacturing and service industries have grown more rapidly.
	Technical Efficiency	Castiglione, 2011	Technical Efficiency	Evidence from MCC database of Italian manufacturing firms from 1995 to 2003 (on a three year level, 1995-1997, 1998-2000, 2001-2003), and the last survey, total no. of firms are 3,452. Results show that ICT investment positively and significantly improves firm's technical efficiency.
	IT and VO adoption	Lin, 2011	Organizational Innovation	Data from 86 information and electronics companies in Taiwan, this study demonstrated that IT and VO adoptions positively affect organizational innovation. Furthermore, IT and VO adoptions also positively moderate the relationship between employees' creativity and organizational innovation.
Returns to Scale	ICT Investment	Rodriguez, 2012	Real Output, Employment and labor productivity	EU-KLEMS database from 1977-2005 on nine EU-15 countries and USA. An increase in ICT investment is positive for the economies of these countries, giving rise to larger growth in real output, employment, and labor productivity at the industrial level. The pattern of responses to changes in ICT investment is quantitatively diverse across most of the EU-15 countries studied and in the two types of industries considered (i.e. ICT-intensive and less intensive industries). Moreover, the positive impact on labor productivity in ICT-intensive industries is larger after the mid-1990s, with the USA being the most positively affected country.
	ICT Spillovers	Han, Chang and Hahn, 2011		Using data from Bureau of Labor Statistics for US manufacturing industries, the impact of IT spillovers on the productivity growth of downstream industries has been examined. Results indicate that downstream industries receive significant IT spillovers in terms of increased TFP but these spillovers are not uniform and come IT intensity and competitiveness of the downstream sector moderate the effects of IT spillovers. Finally Long term spillover effects are greater than short term spillover

				effects indicating learning periods.
	ICT and Regional Complementarities	Iammarino and Lasinio, 2013	Regional Labor Productivity	Using experimental micro data, the paper provides ICT production and regional labor productivity in the 2001-2005 in Italy. A complementary relationship between ICT production and diffusion in explaining interregional differences in productivity growth. Regions that contributed most to aggregate productivity growth are those in which average growth of labor productivity of ICT producing firms was highest.
	ICT investment*	Castiglione and Infante, 2010	Solovian residual in TFP	The paper uses data of two surveys carried out by MCC (1998-2000) and (2001-2003) on Italian manufacturing firms resulting in 4,680 and 3,452 firms where total 1,643 firms were present in both surveys. Result show that both ICT investment and firm efficiency have a positive influence on firm's efficiency
	FDI and ICT investment	Dimelis and Papaioannou, 2010	Productivity growth (various factors)	Panel data covering 42 developed and developing countries during 1993-2001. Growth accounting results indicate growth contribution of ICT was high for both developed and developing countries and the significance remain for all the groups.
	ICT investment	Dimelis and Papaioannou, 2010	Productivity growth	Using industry level data to compare the effects of ICT on producitivty between US and EU, This effect for the EU was strong in the early 90s and weakened afterwards, as opposed to the US where it strengthened in the late 90s. The results of the pooled mean group estimator confirm that the long run growth contribution of ICT was significantly positive in the industries of both regions and over the entire period 1980–2000. However, it seems that the productivity effects of ICT are mainly present in the industries which are either ICT producers or heavy ICT users.
	IT investment	Oliner, Sichel and Stiroh, 2008	Productivity growth at aggregate and industrial level	Central role for information technology (IT) is observed in the productivity revival during 1995–2000 and show that IT played a significant, though smaller, role after 2000. Productivity growth after 2000 appears to have been boosted by industry restructuring and cost cutting in response to profit pressures, an unlikely source of future strength. In addition, the incorporation of intangible capital into the growth accounting framework takes some of the luster off the performance of labor productivity since 2000 and makes the gain during 1995–2000 look larger than in

				the official data. Finally, we examine the outlook for trend growth in labor productivity; the estimate, though subject to much uncertainty, is centered at 2-¼% a year, faster than the lackluster pace that prevailed before 1995 but somewhat slower than the 1995–2006 average.
	ICT investment	Wilson, 2012	Productivity	In an attempt to explore relationship between capital composition and productivity using dataset on firm investment in US in the late 1990s, the study finds that most capital types earned normal returns except ICT capital goods which had marginal products substantially above their rental prices. High tech goods are complements to low-tech goods while substitute for other high tech goods.
	ICT investment	Edquist, 2011	Labor productivity growth	Data on ICT from EU-KLEMS from 1993-2007. The results show that labor productivity growth and the overall contribution to labor productivity growth was considerably higher in technologyproducing industries following the diffusion of ICT. Moreover, the results presented here show no evidence that industries that were early adopters of electric motors and ICT, on average, would have contributed more to productivity growth in Swedish manufacturing.
	ICT capital services per hour worked	Catellacci, 2010	Labor productivity	Using OECD data from 1970 to 2005, the results underscore a superior productivity performance in the sectors close to the new GPT. The key determinants of sectoral productivity dynamics related to technological capability, ability to acquire external knowledge. Long run performance of national economies is related to overall innovation capability, intensity of external knowledge acquisition and ability to undertake a process of structural change in high opportunity sectors.

The studies on Returns to scale provide examples from two or more traits of ICT contribution to growth.

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