CENTRO STUDI LUCA D'AGLIANO

WWW.DAGLIANO.UNIMI.IT

CENTRO STUDI LUCA D'AGLIANO
DEVELOPMENT STUDIES WORKING PAPERS

N. 362

December 2013

A Firm-Level Analysis of ICT Adoption in an Emerging Economy: Evidence from the Colombian Manufacturing Industries

*Juan M. Gallego**
*Luis H. Gutiérrez***
*Sang H. Lee****

* Universidad del Rosario and Centro Studi Luca d'Agliano
** Universidad del Rosario
*** Southeastern Louisiana University

ISSN 2282-5452

A Firm-Level Analysis of ICT Adoption in an Emerging Economy: Evidence from the Colombian Manufacturing Industries

Authors:

1. **Juan M. Gallego**
   juan.gallego@urosario.edu.co
   Affiliation:
   Department of Economics – Universidad del Rosario
   Calle 12c #4-59, Bogotá-Colombia
   Tel: +5712970200 ext 7841

   And

   LdA (Centro Studi Luca d'Agliano)
   Via Conservatorio 7, Milano - Italy

2. **Luis H. Gutiérrez (corresponding author)**
   luis.gutierrez@urosario.edu.co
   Affiliation:
   Department of Economics – Universidad del Rosario
   Calle 12c #4-59, Bogotá-Colombia
   Tel : +5712151734; fax:+5712151734

3. **Sang H. Lee**
   slee@selu.edu
   Affiliation:
   Department of Management and Business Administration
   Southeastern Louisiana University
   SLU-10813, Hammond, LA 70402
   U.S.A.

Abstract

This study examines ICT adoption among 3,759 Colombian manufacturing firms to identify factors that are pertinent to the adoption and usage of ICT at the firm level. This article also attempts to ascertain if the determinants of a firm's ICT adoption vary across the firm size. Our major findings show that three main factors are complementary to a firm's ICT adoption: human capital, organizational changes, innovation results. Also, firms facing competition in markets abroad are more likely to adopt ICT. Information spillover within the industry is also identified as a determinant of ICT adoptions by firms.

Keywords: ICT adoption, Internet, Innovation, Organizational change.

JEL classification: O30

1. Introduction

After a number of empirical studies linked the high performance of the U.S. economy in the 1990s to its widespread adoption of information and communication technologies (ICT) (Berman et al., 1994; Jorgenson and Stiroh, 2000; McGuckin and Stiroh, 2002; Morrison and Siegel, 1997; Siegel, 1997; Stiroh, 2001), much has been debated about the effects of ICT on firm productivity and profitability (Bartelsman and Doms, 2000; Bresnahan and Trajtenberg, 1995; Brynjolfsson and Hitt, 1996; Brynjolfsson and Yang, 1996). On the other hand, the literature on technological changes recognizes the complementary relationship among the adoption and usage of ICT, firm-specific factors, and industrial structure. Since Milgrom and Roberts (1990) pioneered the study on the complementary role of firm-specific operational and organizational characteristics as determinants of the adoption of new information technologies at the firm level, a significant amount of the literature has focused on the identification of the factors that are inherent to varying rates of ICT adoptions across firms (Bocquet, Brossard, and Sabatier, 2007; Bayo and Lera, 2007; Fabiani, Schivardi, and Trento 2005; Giuri, Torrisi, and Zinovyeva, 2008; Hollenstein, 2004; Lucchetti and Sterlacchini, 2004).

Although such evidence was obtained mainly from a handful of developed economies, identifying the complementary relationship among the determinants of ICT adoption factors is a topic of relevance to countries at all different stages of economic development, especially in emerging and developing economies. First, an increasing number of emerging economies have launched information technology (IT) initiatives and established some form of information and communication systems (Udo and Edoho, 2000). Some anecdotal assessments of IT initiatives appear promising in developing countries like China, Chile, Egypt, India (Indjikian and Siegel, 2005), Colombia (Ministerio de Comunicaciones, 2007), and Venezuela (Ministerio del Poder Popular para Ciencia, Tecnología e Industrias Intermedias, 2007). Second, positive impacts on economic performance of ICT observed in developed countries may signify the importance to emerging economies of investments in ICT in their efforts to transition to the knowledge-based economy. Although many emerging and transition countries face relatively high social opportunity costs of investments in ICT, several case studies and anecdotal evidence suggest that developing and transition countries have the potential for productivity gains and economic growth from the ICT adoption and usage (Dutta et al., 2003; Humphrey et al., 2003; Lal, 2004; Moodley, 2002; Udo and Edoho, 2000). Third, most developing or emerging economies are made up of small and medium-sized firms (SMEs). They are typically risk averse as well as lacking financial means and human capital relative to large firms. A better understanding of the accompanying circumstances under which SMEs contemplate technology adoption could be an important policy aspect.

In this article, we analyze the determinants of ICT adoption among 3,759 Colombian manufacturing firms, and we attempt to identify the factors that are conducive to the adoption and usage of ICT at the firm level. This study contributes to the existing empirical literature along several margins. First, we have taken the complementary view approach to examine a firm's decision-making process to adopt the ICTs. In order to achieve this goal, we have considered three groups of potential determinants of the ICT adoption: i) we measure whether the firm had implemented an organizational change or an innovation decision in the period before it adopted ICTs so that we are able to link innovation and organization changes with the information technology adoption at the firm level in a developing country; ii) we also analyze the relationship of employees' human capital and ICT adoption rate for firms within an economy where the skill levels of the workforce are low compared to those in the developed economies;

iii) finally, we have examined how firm and industrial characteristics are related to the adoption decisions in terms of the well-known technological diffusion approach. The study of these potential determinants of ICT adoption at the firm level is expected to give us a better understanding of a firm's ICT adoption decision-making process, especially in light of the complementary approach.

Another contribution to the literature of this study is twofold: first, building upon Corrocher and Fontana (2008) that several technologies might be adopted by a firm on different ways and in several cases in bundles, we explore the hypothesis that a firm's adoption of a particular ICT might be influenced by other ICTs the firm has already adopted. Put differently, we assume that there exist potential correlations when a firm adopts more than one type of ICT. In order to take into account such potential simultaneity or contemporaneous correlations in a firm's ICT adoption decisions, we employ a seemingly unrelated regression (SUR) model. Furthermore, to test the robustness of the explanatory variables in the regression, we have built an index of ICT adoptions by firms using a Principal Component Analysis. We first regress the ICT index by ordinary least squares on the same explanatory variables controlled for in the SUR model, and then fit a Tobit model, because some firms have not adopted ICTs and thus are truncated at zero.

Third, to our best knowledge, the existing studies in the literature of the ICT adoption have thus far focused only on developed countries such as United States, United Kingdom, Ireland, Italy, South Korea, Spain, Switzerland, and so on. This study differs from the existing literature and provides different perspectives on a firm's ICT adoption process, because it examines the determinants of ICT adoption at the firm level in the developing economy, Colombia, where its ICT industry is at the inchoate stage of development and the manufacturing sector is largely consisting of small or medium-sized firms. Although Commander et al. (2011) recently studied the relationship between the ICT adoption and productivity for Brazil and India, the two countries are much different from a developing economy like Colombia in that Brazil and India are two of the most dynamic emerging economies that have been experiencing vibrant economic growth, particularly in the ICT sectors.[1] In addition, Commander et al. (2011) provide little insight on the determinants of the ICT adoption at the firm level.

[1] The Brazilian ICT industry represented about 7 % of its GDP in 2011, and about 6.1% of India GDP in 2010 (Simon, 2011). In Colombia the industry is under developed being its contribution less than 1%.

Drawing on large databases from the Colombian Bureau of Statistics (Departamento Nacional de Estadística - DANE), we first construct a number of ICT indicators that are representative of Colombian manufacturing firms across industries, geographical areas, and sizes. With different information technology adoption measures as dependent variables, we then develop a basic empirical model which investigates not only the complementary relationship between the ICT adoption and a set of firm-specific external and internal factors, but also the effects on a firm's ICT adoption of the information spillover among early ICT adopters and potential users (Griliches, 1957; Mansfield, 1961 and 1989). Our major findings are (i) that the adoption of a given information and communication technology is better facilitated when a firm with a large stock of human capital engages more in innovative activities, and when its organizational structure is better aligned with the given technology; (ii) that positive associations between the key determinants and ICT adoptions are more pronounced in Colombia for small and medium-sized firms than for large ones, and (iii) that information spillover within industries is also a significant determinant of ICT adoptions at the firm level.

The rest of this study is organized as follows. In the following section, we review the literature on the ICT adoptions and develop the theoretical framework for the study. After we define ICT adoption indicators and explanatory variables in Section 3, we describe our data and empirical strategy in Section 4. Finally, we present our empirical findings in Section 5 followed by concluding remarks in Section 6.

2. Empirical background and theoretical framework

The literature on the adoption of ICTs has documented a vast amount of empirical evidence of various factors that are inherent to a firm's ICT adoption. For instance, the inter-firm technological diffusion approach has focused largely on three aspects of the process. First, the so-called rank effects argue that a firm's decision to adopt new technologies may be guided by some firm characteristics that affect its profits and hence its incentives to innovate. Second, the stock effects that early adopters' stock of technologies eventually affect negatively the expected returns to ICT investments of new adopters, so that new potential adopters are likely to refrain from adopting new technologies or adopt them on a lower scale. Lastly, the adoption of any new technology leads to an order effect that early adopters obtain higher returns from the technology adoption than later adopters and non-adopters (Karshenas and Stoneman, 1993; Battisti and

Stoneman, 2003, 2005; Battisti, Hollenstein, and Woerter, 2008; and Battisti, Canepa and Stoneman, 2009).

Another theoretical view focuses on the complementarity of the introduction of any new technology with a firm's organizational design and knowledge capabilities (Milgrom and Roberts 1990, 1995; Stieglitz and Heine, 2007; Caroli, Greenan, and Guellec, 2001). In this view, the success in adopting any new technology and its further impact on productivity is basically determined by the presence of proper key elements such as organizational technologies, skills, and innovation efforts. Those elements once properly introduced in the firm structure allow a smooth adaption process of new technologies.

Combining these different theoretical views, we first review the following five underlying determinants of a firm's ICT adoption that we consider relevant to our study in the Colombian manufacturing industry: human capital, internal organizational characteristics, a firm's structural characteristics, the effects of ICT information spillover, and the characteristics of industrial environment. These determinants have been debated and tested in the recent empirical studies and we pose testable hypotheses about them.

Human capital

A crucial implication of ICT adoption at the firm level is that the implementation of new technologies in an organization is influenced by individual traits of employees such as the educational attainment. As for the educational level of workers, a common proposition in the literature has been that ICT investment and adoption at the firm level can be facilitated when a firm's workforce is comprised of a relatively large number of high-educated (or high-skilled) workers, because the ICT usage and its impact on productivity are likely to increase with the number of workers with higher educational attainment. Learning capabilities can be considered complementary inputs to the innovation-adaptation process as well as to the production within a firm because they allow the firm to efficiently assimilate new knowledge and facilitate learning. Such complementary relationship between the adoption of ICT and the educational level of workers has been evidenced in a large number of studies (Arvanitis, 2005; Bayo and Lera 2007; Black and Lynch, 2004; Bresnahan et al., 2002; Chapman et al., 2000; Fabiani et al., 2005; Haller and Siedschlag, 2011; Lucchetti and Sterlacchini, 2004; Parente, 1994; Perez et al., 2005; Yap et al., 1992).

Internal organizational structure and innovation

Another main aspect of the complementarity view in the literature of the ICT technology adoption has been the relationship between the adoption of ICT and the organizational characteristics of a firm. A primary reasoning behind the organizational complementarity is two-fold. First, the adoption of ICT is likely to be facilitated when a firm's decision-making process is decentralized and when its organizational structure is made up of reduced hierarchical levels. This is because productivity gains from ICT adoption are expected to be greater when such decentralized and de-layered organizational structure allows for increased information sharing and more effective involvement in decision making among employees (Bayo and Lera, 2007; Black and Lynch, 2004; Bocquet, O. Brossard, 2007; Bruque and Moyano, 2007; Bresnahan et al., 2002; Bugamelli and Pagano, 2001; Caroli and Van Reenen, 2001; Fabiani et al., 2005; Falk 2005; Giuri et al., 2008; Williams, 1994). Secondly, several studies have focused on a reverse organizational complementarity that runs from the adoption of ICT to organizational changes (Aghion, 2002; Bresnahan and Trajtenberg, 1995; David and Wright, 1999; Giuri et al., 2008). For example, Giuri et al. (2008) argues that the new systems of production may lead to reorganization of workplace as a secondary innovation, because new technologies often increase the benefits and reduce the costs of decentralization and reduced hierarchical layers. As for the diffusion approach, some interesting insights have been forwarded to analyze the relation between ICT and organizational changes: a positive influence can be more "likely in case of intra firm than inter firm diffusion since adoption costs are much higher if a thorough redesign of a firm's reorganisation is required than for an incremental adjustments of organisation which, in most cases, are sufficient at the stage of (first) adoption" (Battisti et al, 2007). Although the ICT adoption at the firm level is more often than not related to the intra-firm technology adoption or diffusion, empirical findings are mixed and remain controversial in the literature.

Another important complementarity factor of ICT adoption is innovation efforts. It is obvious from the production point of view that ICTs are closely related to productivity since they are investment goods that firms will substitute for labor or other types of capital goods if the prices of ICTs become relatively cheap (van Leeuwen, 2008). Somes studies (Black and Lynch, 2000; Bresnahan, Brybjolfsson, and Hitt, 2002; and Hempell, 2006) show that increased ICT adoption and usage not only enhance internal business process, but also promote business-to-

business and business-to-client communications, leading to (wider) networks or spillover effects. Therefore, it might be presumed that the likelihood of ICT adoption by a firm increases as more firms engage in innovative processes.

Structural characteristics of firms

One of the most commonly tested hypotheses in the literature is that the size of a firm is positively correlated to ICT adoption with the presumption that larger firms can afford to devote more capital and resources to the adoption of ICT than smaller ones. For instance, Premkumar and Roberts (1999) and Geroski (2000) suggest that, given high risks and large costs associated with early adoption of ICT, larger firms are better positioned to take the initiatives in deploying new technologies. In a similar context, Cohen and Levin (1989) argue that large firms are more likely to adopt ICT as they are better prepared to absorb the financial burden of large up-front investment expenditures in ICT thorough economies of scale. Another interesting contribution to the literature in this regard is Hollenstein (2004). Based on a large number of observations on the ICT adoption behavior of Swiss business firms, the study confirms that medium-sized firms have the highest likelihood of ICT adoption. Although a few studies find that the size of firms is either irrelevant or even adverse to firms' ICT initiatives (Battisti et al, 2007), the main findings in the literature are in support of a positive correlation between the ICT adoption and the size of firms (Battisti et al., 2009; Gretton et al., 2004; Kowtha and Choon, 2001; Lucchetti and Sterlacchini, 2004; Morikawa, 2004).

In addition to firm's size, some studies in the literature have focused on a positive role of multinational ownership in firms' incentive to adopt ICT for the following economic reasoning. First, firms under multinational ownership have not only more financial resources for investments in ICT (Westphal et al., 1997) but also a relatively strong risk management system (Indjikian and Siegel, 2005). Second, multinational firms tend to be more open to external factors (Lai and Guynes, 1997) and benefit more than domestic firms from ICT adoption through enhanced coordination of business activities (Akmanligil and Palvia, 2004; Galliano et al., 2001). Third, multinational firms or its subsidiaries in developing countries can be early adopters of new technologies because of the augmented market access that comes with foreign ownership which allows them to have greater benefits or to have lower costs (Guadalupe, Kuzmina, and Thomas, 2012).

Epidemic effects (information spillover)

While the complementarity view emphasizes the factors inherent to a firm's structural and organizational characteristics in relation to the firm's ICT adoption decision, the epidemic approach in the literature has focused on the process of technology diffusion across firms within an industry with the presumption that, if the frequency of contacts between current ICT adopters and potential users increases, so does the likelihood that a firm learns more about a new technology as more firms adopt the technology (Griliches, 1957; Mansfield, 1961, 1963, and 1989). Mansfield (1963), for instance, assumed that the speed at which a technology spreads across firms depends on several firm characteristics such as the number of current users of the technology and the profitability of the technology adoption. However, empirical findings in the literature on the inter-firm technology diffusion are not unanimous, suggesting that information spillover (or information acquisition) alone may not fully explain the transfer of a technology across firms (Antonelli, 1989; Karshenas and Stoneman, 1993; Colombo and Mosconi, 1995; Swamidass, 2003; Battisti, 2008; Battisti et al., 2007; Battisti et a., 2009).

Industrial environment

A firm's incentive to adopt ICT may also be affected by the local industrial or market structure (Battisti and Stoneman, 2010; Bayo and Lera, 2007; Haller and Siedschlag, 2011). Considering that a firm's decision to undertake investments in innovative technologies is ultimately influenced by the potential profitability of such investments, industrial characteristics pertaining to the firm's profitability prospect will become presumable factors in ICT investment decisions. The industrial characteristics that have been commonly recognized in the literature as key determinants of ICT adoption include the level of local competition, industry-specific technological opportunities, and the global aspect of the market.

As for the level of competition in a local market or industry, a prevailing presumption in the literature has been that a firm under high competitive pressure is more likely to invest in new technologies as a way of maintaining its competitive edge over rivals. Measures of competitive pressure vary across different studies. For instance, Battisti and Stoneman (2010), Bayo and Lera (2007) and Baldwin et al. (2004) use a binary variable whereas Hollenstein (2004) captures a firm's export-to-sales ratio as a proxy for competitive pressure. A large number of empirical

studies have confirmed a positive role of local competition in the ICT adoption at the firm level (Baldwin et al., 2004; Bayo and Lera, 2007; Bertschek, 1995; Gattington and Robertson, 1989; Haller and Siedschlag, 2011; Hollenstein, 2004).

Several studies have also attempted to link industry-specific technological opportunities to the likelihood of the ICT adoption at the firm level. Propitious industrial environments for the adoption of new technologies have been incorporated into empirical studies in several forms. For instance, Hollenstein (2004) uses firm's assessment of the potential to use ICT on a 5-point Likert scale while Bayo and Lera (2007), Fabiani et al. (2005), and Lucchetti and Sterlacchini (2004) use binary variables to differentiate individual firms across different industries. It is also worth noting that Fabiani et al. (2005) controls for geographical locations of establishments as a way to examine the effect of interactions among firms on the ICT adoption. And Haller and Siedschlag (2011) found that geographic locations did not affect the probability of firms having a website, but it did affect the probability of accepting orders on line. They suggest that firms located in a region and industry where there are large firms have better probabilities of accepting online orders.

Another interesting aspect pertaining to the relationship between industrial environment and ICT adoption is that firms in international markets are more likely to invest in information and communication technologies because they have a strong incentive to reach new customers worldwide via the Internet-based technologies. A positive relationship between the ICT adoption and the global aspect of the market has been evidenced in many empirical studies (Braga and Willmore, 1991; Fabiani et al., 2005; Hollenstein, 2004; Kumar and Saqib, 1996; Teo and Pian, 2003).

Building upon the existing theoretical views and the empirical works in the literature on the ICT adoption at the firm level, this paper attempts to identify the underlying key determinants of firms' ICT adoption in the Colombian manufacturing sector by posing the following two testable hypotheses:

Hypothesis 1: We presume that the stock of human capital, organizational technologies, and innovation efforts of a firm are complementary to the adoption of information and communication technologies (ICTs) by firms.

Hypothesis 2: We presume that the complementarity factors affecting ICT adoptions outlined in hypothesis 1 are usually more difficult to implement in small and medium-sized firms than in large firms. We, however, expect that the complementary effects of human knowledge and skills, organizational technologies, and innovation would be pronounced more for small and medium-sized firms than for large firms once they are successfully implemented.

3. Variables

3.1 Dependent variables: ICT accessibility and usage indicators

In order to assess the adoption and usage of ICTs both at an individual worker level and at the firm level, we take into account nine ICT indicators in three different groups as follows.

ICT accessibility and usage indicators at the individual worker level

We first consider three ICT indicators that refer to the direct access to and usage of basic ICTs by employees of a firm. The variable *PC_per_employee* is one of the most common measures of ICT accessibility by a worker and is obtained by dividing the number of a firm's PCs by the number of its employees. Another variable *PC_users* refers to the percentage of a firm's employees who use PCs specifically for their routine tasks. This variable differs from *PC_per_employee* and is expected to provide us additional insights on the determinants of ICT adoption, because PCs may not be required for all employees to perform their regular tasks.

The last ICT indicator at an individual worker level is *PC_users_internet* and it refers to the percentage of employees who use PCs connected to the Internet. While it seems more apparent that people in sales department or in the management are more prone to using the Internet for their daily tasks, some engineers and technical workers may also need to be interconnected via the Internet.

ICT accessibility and usage indicators at the firm level

The second group of ICT indicators consists of two dummy variables: (i) whether a firm has access to the Internet (*internet_access*) and (ii) whether a firm has its own registered website (*webpage*). Each binary variable takes on the value one if the firm has the underlying technology and zero otherwise. Basic Internet access being considered as an off-the-shelf technology, the variable *internet_access* is expected to show little variation across the size, regional location, or

technology-intensiveness of a firm. However, the variable *webpage* is presumed to be positively correlated with a firm's size or technology-intensiveness, because large and technology-intensive firms may find higher inherent value in the use of a webpage than otherwise.

ICT-intensiveness indicators at the firm level

This group consists of three ICT indicators that refer to the extent of ICT use by firms. We first define the categorical variable *internet_areas* which measures the number of functional areas of a firm's business where the Internet is used. To do so, we divide a firm's operation into three functional areas such as sales, production, and management. For instance, if a firm uses the Internet in all three functional areas of its operation, the variable will take on the value three. The greater is the value of the variable for a firm, the higher is the degree of intra-firm diffusion of the Internet technology.

Another indicator for a firm's ICT-intensiveness is the variable *internet_apps*. This categorical variable measures the number of responses by a firm to the questions whether the Internet is used for (i) ordering raw material, (ii) selling products, (iii) electronic banking, (iv) providing services to customers, and (v) distributing products on line. For each question, this indicator takes on the value one if the firm responds with "yes" and zero otherwise. Therefore this composite indicator takes on a value between zero and five. Similarly, we define the variable *networks* by adding up three binary responses to three questions: whether a firm has (i) Intranet, (ii) Extranet, and (iii) LAN, respectively. For a firm's positive response to each question, the variable takes on the value one and zero otherwise. Thus, if a firm has all three forms of networks, the variable *networks* will take on the value three. All three categorical variables are presumed to be positively correlated with firm size, human capital, innovative organizational changes and process-related innovations of a firm.

Some ICTs may be adopted sequentially one after another or simultaneously in a bundle depending on a firm's internal and external characteristics and industry environments. As Battisti, Canepa, and Stoneman (2009) argued, a sophisticated process may exist by which ICT has been adopted and used by firms. Since this study uses databases from the Colombian Bureau of Statistics that provides just a snapshot of ICT adoption by firms, we proceed to build a composite ICT index of the aforementioned eight ICT indicators to examine the likelihood that those ICTs could have been adopted as a bundle. This reasoning is reinforced by commercial

strategies pursued by Internet service providers as well as by domain registration companies that bundle services to residential and commercial users. In addition, the utilization of a composite ICT index may serve as a way to check the robustness of the determinants of the ICT adoption decisions by firms. We take advantage of the statistical information contained in our data set by building a composite ICT adoption index. In particular, we implement a statistical procedure of principal components to determine the weights for an index of the eight ICT variables. By using the principal component analysis (PCA), we can capture the largest amount of information on the adoption of ICTs that all ICT adopters share in common. We implement the same procedure of the principal component analysis used in the literature of family asset index and wealth index in which the first principal component of a set of variables is a linear index of all the variables with the largest amount of common information (see Filmer and Pritchett, 2001 for a complete discussion on wealth index using the PCA).

3.2 Explanatory variables

For a better understanding of a firm's ICT adoption decision-making process both from a complementarity view as well as from a technology diffusion approach, this study considers a firm's stock of human capital, its past experiences in innovative organizational changes or process-related innovations, inherent structural characteristics, and the industrial environment in which a firm operates as follows.

Organizational changes and innovations

The Colombian Innovation Survey (EDIT II) surveyed firms about whether they made investment in any of the five technologies of organizational tools: (i) quality management of products, (ii) Kaisen, (iii) total quality management (TQM), (iv) the enforcement of ISO (international organization for standardization) norms, and (v) other technologies such as good manufacturing practice (GMP), hazard analysis and critical control points (HACCP). We created a binary variable (denoted by *org_change*) which equals to one if a firm invested at least in one of the five technologies and zero otherwise. It is worth stressing that some research has highlighted concerns over the appropriate timing of the adoption of ICTs and organizational changes. In that regard, we presume that any successful implementation of ICTs within a firm's work system shall be preceded by corresponding organizational changes.

In addition, we presume that ICT adoptions are more likely to happen in firms that have successfully introduced either product innovation or process innovation, and thus control for a binary variable (denoted by *innovation*) which equals to one if a firm performed either product or process innovation during the year 2004 and zero otherwise.

Human capital

As discussed previously, a firm's human capital is considered a factor that either facilitates or hinders the adoption and facilitation of ICTs in that a firm's capacity to benefit from ICTs is potentially limited by its human capital. In this study we employ two measures of human capital at the firm level: the percentage of workers with a bachelor's degree or higher (denoted by *college*) and the ratio of number of employees with post secondary education in technical institutions to total employees (denoted by *technician*).

Characteristics of firms and industrial environments

This study also employs a set of variables that are believed to be inherent to a firm's structural characteristics and the industrial environment in which a firm operates. With regard to a firm's structural characteristics, we first control for a firm's size (denoted by *size*) by using the logarithm of a firm's sales as a proxy for it. Second, the presence of foreign ownership is controlled for by a binary variable (denoted by *foreign_own*) that takes on the value one if foreign capital accounts for at least one percent of a firm's total ownership.

As for the industrial environment in which a firm operates, we control for the global aspect of industrial environment (denoted by *exp_sales*) using a firm's export sales as a percentage of its total sales. The economic reasoning behind this is that firms competing in international markets are more likely to adopt ICTs because they have a strong incentive to reach new customers worldwide via the Internet-based technologies.

Another important aspect of the ICT adoption by the firm that has been extensively examined in the literature is the information spillover or epidemic effects (Hollenstein, 2004; Battisti and Stoneman, 2003; Battisti et al., 2007; Hollenstein and Woerter, 2008). Hollenstein (2004, p.319) articulates "The epidemic model basically states that a firm's propensity to adopt a technology at a certain point in time is positively influenced by the present (or lagged) level of diffusion in the economy as a whole, or by the proportion of adopters in the industry or sector to

which the specific firm is affiliated." Although different indicators have been proposed in that literature, we build upon Hollenstein (2004) and construct a simple indicator (denoted by *spillover*) of the epidemic effect by calculating the average of each ICT indicator across the manufacturing sector to which the firm is affiliated and across geographic regions it is located to as follows:

$$\overline{Y}_{jr}^{k} = \frac{\sum_{i \neq l=1}^{N-1} Y_{jr}^{l}}{N_{jr}}$$

In the indicator above, Y refers to one of the eight ICT technologies aforementioned, j indicates the manufacturing sector and r the region to which firms i and l belong. The numerator shows the number of firms excluding firm i that have adopted the technology Y while the denominator is the total number of firms in that sector and region. Thus, for the given technology Y, the epidemic effect in sector j and region r is proxied by the sector- and region-specific level of diffusion of the technology relative to firm i. This variable is controlled for in all regressions as an additional explanatory variable for the adoption of an ICT by firms.

Finally, we included a set of dummy variables for five broad Colombian regions (denoted by *region*) as well as for three levels of technology aggregation of manufacturing firms (denoted by *tech_agg*). The five broad Colombian regions are: the Caribbean region composed of seven regional states, the Pacific region composed of three states, the Coffee region composed of fours states, the Central region composed of six states, and Bogota, the capital of the country. The level of technology aggregation of a firm is identified according to the OECD low, medium-low and medium-high technology aggregations of manufacturing based on Standard International Trade Classification (SITC Rev. 3).

<Place Table 1 Description of Variables here>

4. Data and empirical strategy

4.1 Data

Our empirical analysis uses two sources of data. As mentioned in the first section, the basic ICT-related quantitative data are drawn from the Colombian Manufacturing Survey (Encuesta Anual Manufacturera - EAM) conducted yearly by the Colombian Bureau of Statistics

(Departamento Nacional de Estadística - DANE) since at least 1970. The survey is carried out on all Colombian manufacturing firms with 10 employees or more. The number of firms included in the manufacturing survey was 5497 out of 7639 establishments for the year 2006. The database for this study is ample and represents a significant portion of the Colombian manufacturing firms across industries, geographical areas, and sizes. The survey collects information on more than 200 variables, but the DANE only provided us with only a subset of the data. The EAM comprises quantitative variables on production, sales, number of employees, capital investment, percentage of sales exported, and the like. The main reason for this study to employ the 2006 survey results is that it was the first survey that included an special requesting information on the access to and usage of ICTs by employees, adoption of network technologies, and use of the ICT network for business activities. As shown in Table 2, small and medium firms represent about seventy-two percent of the sample firms in our data set. The distribution of firms across manufacturing sectors is heavily centered on food and tobacco, textiles and leather, and chemicals products. Also, most firms are located in Bogotá and the so-called Coffee zone.

Table 2 also shows a couple of notable observations on the statistics. First, a high degree of heterogeneity has been observed in all ICT indicators across different aggregations of manufacturing as well as across regions. Second, the descriptive statistics reveals that the Colombian manufacturing firms are quite behind their international peers in overall use of ICTs as evidenced by Bayo and Lera (2007) and, Haller and Siedschlag (2011). For instance, in Ireland, the PCs per employees is over 31%, and 37% of firms with at least 20 employees or more have a website. This observation certainly provides a further rationale for the study on the key determinants of ICT adoption by Colombian manufacturing firms. We take advantage of the variation of the technology indicators, as shown in the table 2, to build the rate of adoption at the industry and regional cell.

<Place Table 2 Descriptive statistics here>

The second source of information is the Colombian Innovation Survey II (Encuesta de Innovación y Desarrollo Tecnológico – EDIT II) also carried out by the DANE. The EDIT II requested information for the years 2003 and 2004 about decisions to invest in innovation process as well as if the firm introduces a new innovating product or service to the market or to

the firm and if the firm has introduced a new innovation production and organizational process. In addition the survey also collects information on employees' human capital and organizational features. At the matching process of the two surveys, using the identification key provided by the DANE, we excluded (i) firms with missing values of main variables in any of the two surveys, (ii) firms with abnormal figures either for ICT indicators, sales, investment in ICTs, exports, or for any explanatory variables used in the regressions, and (iii) firms with fewer than 10 employees. After the detection and correction of missing values and outliers in the survey observations, 3,759 sample firms were included in this study. The available information is to a large extent quantitative in nature.

4.2 Empirical strategy

Based on the recent development in theories and empirical evidence in the literature of the ICT adoption with the presumption that ICTs may be adopted sequentially one after another or simultaneously in a bundle depending on a firm's internal and external characteristics and industry environments, we fitted a seemingly unrelated regression model as follows (Wooldridge, 2007, Chapter 7):

$$Y_{ij}^{k} = \beta_0 + \boldsymbol{X}_{ij}\boldsymbol{\beta} + \alpha_1 \bar{Y}_{jr}^{k} + \alpha_2\, org\_change_{ij} + \alpha_3\, college_{ij} + \alpha_4\, technician_{ij} + \alpha_5\, innovation_{ij} + \theta\, tech\_agg_{i} + \eta\, region_{i} + \varepsilon_{ij}^{k}$$

where k=1, 2, ⋯, 8.

In the model above, i refers to a firm, j denotes the manufacturing sector the firm is affiliated with, r denotes the region where the firm is located and, k the ICT variable that was adopted. $\boldsymbol{X}$ is a vector of control variables that includes the logarithm of a firm's sales (*size*), a firm's exports as a percentage of its total sales (*exp_sales*), the presence of foreign ownership (*foreign_own*), and the *CR4*, which is the four-firm concentration ratio that measures the share of total output accounted for by the four largest firms in the manufacturing sector j where the firm i is affiliated. $\bar{Y}_{jr}^{k}$ is the spillover effect of the ICT diffusion and is measured as the share of ICT adopters (except firm i) of technology k in manufacturing sector j in region r.

The binary variable *org_change* indicates whether a firm invested at least in one of the five technologies of organizational tools in the previous period. The variable *college* is the percentage of workers with a bachelor's degree or higher and the variable *technician* is the ratio of number of technicians to total employees. The binary variable *innovation* indicates if a firm performed either product or process innovation during the year 2004. The variable *tech_agg* is a set of dummy variables for three levels of technology aggregation of manufacturing firms, each of which refers to whether the firm *i* is located in medium-high, medium-low or low technological sector[2]. Finally, the variable *region* is a set of dummy variables that control for the location of the firm *i* among the five broad Colombian regions. The estimates in the model above will be calculated with robust standard errors clustered by Colombian industrial sectors.

5. Empirical results

The two hypotheses described in Section 2 are tested. We first present the regression results for the sample as a whole. Then we divide the sample into two subsamples: large firms only and small and medium-sized firms only[3] for two reasons: (i) the Colombian manufacturing sector is mostly composed of small and medium-sized firms and (ii) we presume that the extent to which human knowledge and skills, organizational technologies, or product- or process-related innovation is complementary to a firm's ICT adoption may be different for large firms relative to small and medium-sized firms (Hypothesis 2). To test the two hypotheses, we fit Seemingly Unrelated Regressions (SUR) to take into account the possibility that error terms can be correlated across the equations. We also test the robustness of our results using a composite ICT index discussed in Section 3 by fitting both OLS and Tobit regressions.

5.1 Individual ICT adoptions by firms

Each of the eight ICT indicators (dependent variables) is examined by controlling for a set of explanatory variables to see if any of the explanatory variables are complementary to ICT adoption by firms. Table 3 reports the results of the SUR estimation for individual ICT

[2] See Hatzichronoglou (1997). SITC Rev. 3 stands for standard international trade classification. Hatzichronoglou classifies industries in four groups based on technological intensity. Only three of the four groups were included in this study, because the number of Colombian manufacturing firms that belong to high technology intensity group was too small to make any statistical inferences.

[3] Following the Colombian legal framework mandated by Law 905 of 2004, we split the whole sample into two subsamples: a subsample of small and medium-sized firms with at least 10 but no more than 200 employees and the other subsample of large firms with more than 200 employees.

indicators. A notable observation is that the adoption of each ICT by firms is positively influenced by human capital, organizational changes, product- or process-related innovation, and spillover effects.

Consistent with the empirical findings in previous country-specific studies of Fabiani et al. (2005) and Haller and Siedschlag (2011) as well as the theoretical analysis of Cohen and Levinthal (1989), the two measures of human capital at the firm level – *college* and *technician* – are estimated to be the two most significant factors in the adoption of *any* ICT by firms. Furthermore, the variable *college* (the percentage of workers with a bachelor's degree or higher) appears to have the larger impact on any ICT adoption by firms than the variable *technician* (the ratio of number of technicians to total employees). This result evidences that a firm's ICT adoption is influenced more by the human capital in general knowledge and skills than the skill-specific human capital. For instance, a firm with a higher percentage of the labor force with a university degree is likely to use the Internet in more functional areas such as management, sale, and production (*internet_areas*). Besides, a firm with a greater stock of human capital is likely to adopt more Internet applications (*internet_apps*) as well as to stay connected with the outside stakeholders such as suppliers, consumers, investors, and governments (*networks*). This finding reinforces the importance in the ICT adoption of human capital at the firm level and is consistent with the notion of absorptive capacity by Cohen and Levinthal (1990). For the Colombian manufacturing firms in the sample, the average percentage of workers with a university degree or higher was about 14.2% while technicians accounted for on average 16% of total employees.

<Place Table 3 here>

A firm's past experiences in organizational changes and/or product- or process-related innovations also appear to facilitate the adoption of some ICTs. First, six ICT usage indicators except *PC_per_employee* (the number of a firm's PCs divided by the number of its employees) and *PC_users* (the percentage of a firm's employees who use PCs specifically for their routine tasks) are positively associated with the variable *org_change* (a binary response to the question of whether a firm has implemented any of the five technologies of organizational tools defined in Section 3). This result is consistent with the findings in the literature on the relationship between ICT adoption and productivity that the likelihood of adopting some ICTs is greater when a firm

previously implemented organizational changes that are complementary to technologies (Gutiérrez, 2011). In addition, the variable *innovation* (whether a firm has successfully introduced product- or process-related innovations) is also positively correlated with the adoption of the six ICTs except for *internet_access* (whether a firm has access to the Internet) and *PC_users_internet* (the percentage of employees who use PCs connected to the Internet). About 31.5% of the manufacturing firms in the sample invested at least in one of the five technologies (*org_change*) and 63% of the sample had some forms of product- or process-related innovation activity in the year 2004.

Some characteristics of firms, related to rank effects in the diffusion literature, also appear to be important drivers in ICT adoption decisions by firms. The estimation results over the entire sample indicate that firms with a relative high ratio of exports to sales (*exp_sales*) are more ICT-intensive, implying that more internet applications (*internet_apps*) are used in more functional areas (*internet_areas*) with greater networking capability (*networks*). This finding is also consistent with the presumption that firms competing in international markets have a greater incentive to invest in ICTs to stay connected to global customers. About 6.2% of the firms in our study derived a portion of their annual sales revenues from exports to other countries.

Estimated spillover effects are positive and statistically significant, implying that the greater the number of firms that adopted a given ICT, the more facilitated is the adoption of technology by peer firms within the manufacturing sector. However, the presence of foreign capital in a firm's ownership (*foreign_own*), degree of technology aggregation (*tech_agg*), and the level of market concentration (*CR 4*) appear to have a limited impact on ICT adoption decisions by firms.

5.2 Do ICT adoption patterns vary with the firm size?

To see how explanatory power of each control variable distinctively varies with the firm size, we split the whole sample into two subsamples – small and medium-sized firms (SMEs) and large firms only. Table 4 shows the estimation results for small and medium-sized firms while Table 5 for large firms only. When the logarithm of sales was used as a proxy for the firm size, small firms, medium-sized firms, and large firms accounted for about 32.5%, 42.4%, and 25.1% of all firms in the sample, respectively.

There are noticeable differences in estimation results between the two subsamples in terms of the magnitude of the estimated coefficients as well as statistical significance. First, the two measures of human capital at the firm level – *college* (the percentage of workers with a bachelor's degree or higher) and *technician* (the ratio of number of technicians to total employees) – are estimated to have positive and statistically significant effects on the adoption of each ICT by small and medium-sized firms. However, the estimated coefficients of the two variables are not always statistically significant for large firms. Second, the estimated coefficient of the variable *college* is consistently larger than that of the variable *technician* across all ICT adoptions by small and medium-sized firms. This result presents an important policy implication for small and medium-sized manufacturing firms in Colombia – the effect on the ICT adoption of expanding on-the-job training as well as higher education opportunities is greater for small and medium-sized firms than large firms.

A firm's past experiences in organizational change (*org_change*) and in product- or process-related innovations (*innovation*) are estimated to be positive and statistically significant determinants of most ICT adoptions for small and medium-sized firms.

Another salient observation is that the estimated coefficients of the spillover effects are statistically significant across all ICTs for small and medium-sized firms. And the estimated spillover effects are also greater in magnitude for small and medium-sized firms than for large firms, respectively, implying that firms located in a region and/or industry where a high percentage of firms have already adopted a certain ICT are more likely to adopt the technology than otherwise. The results are consistent with the finding of Corrocher and Fontana (2008) that the likelihood that small and medium-sized firms adopt a certain ICT increases in the presence of spillover effects, because their perceived utilities or benefits from the ICT adoption increase as more firms adopt the technology. The fact that nearly 75 percent of the Colombian manufacturing firms were small or medium-sized in the sample data may hold important public policy implications for policies which incentivize SMEs to adopt new technologies, because the adoption or promotion of new technologies is likely to accelerate among the Colombian manufacturing firms due to potentially significant spillover effects.

Although our measure of the spillover effects captures two intertwined epidemic effects in terms of the prevalence of a particular ICT adoption by other firms as well as regional agglomeration of manufacturing firms, certain caveats need to be added to the estimated

spillover effects, especially for small and medium-sized manufacturing firms in Colombia.[4] A key presumption in this study is that the process of adopting and integrating new ICTs into an existing infrastructure is to some extent evolutionary. It is also highly unlikely that firms adopt a particular ICT at the same time. Thus inter-firm technology diffusion can be considered a dynamic phenomenon and will certainly be better understood when a firm's ICT adoption is explained by some cross-sectional and time-varying observations which a cross-sectional data lacks.

<Place Table 4 and Table 5 here>

5.3 A robustness check

Table 6 presents the estimation results with the composite ICT adoption index as the dependent variable for three subsamples: all sample firms, large sample firms only, and small and medium-sized sample firms only. Consistent with the previous findings, human capital (*college* and *technician*), product- or process-related innovations (*innovation*), global perspective of a firm (*exp_sales*) are all positively and statistically significantly correlated to the composite ICT adoption index. The findings remain consistent regardless of the sample size. However, the impact on the ICT adoptions of the four variables is pronounced more for small and medium-sized firms than for large firms. This particular finding may be attributed to the following facts. First, many ICTs in Colombia have not fully matured yet, especially for small and medium-sized firms. Second, firms of different sizes may be at different stages of development and thus have varying needs for ICTs. For instance, changes in human capital, organizational changes, or innovations may have larger impacts on the ICT adoptions by small and medium-sized firms than by large firms that have already adopted certain network technologies.[5]

[4] The authors are grateful to an anonymous referee for the valuable comments and suggestions on a potential endogeneity issue regarding the spillover effects. Since our study uses a cross-sectional data, it is inherently limited in ways to measure the extent of spillover effects in ICT adoption by firms. In an effort to mitigate the limitations imposed by the absence of cross-sectional and time-varying covariates in our sample data as well as to examine the extent to which the spillover variable may represent some missing variables related to ICT adoption by firms, the regression model was fitted with and without spillover effects, respectively. Although the results are not reported here, economic and statistical significance of the estimated coefficients of the explanatory variables was little changed.

[5] There was little variation in the sign, magnitude, and statistical significance of the estimated coefficients of the four variables when the model was fitted with and without spillover effect, respectively.

<Place Table 6 here>

6. Concluding remarks

The primary purpose of this research is to investigate a firm's ICT adoption process based on a large sample of 3,759 Colombian manufacturing firms in the year 2006. The data employed is quite comprehensive in terms of firm sizes, regional locations, and technology aggregations of manufacturing sectors.

We have found robust and persistent empirical evidence that helps us understand the key determinants in the ICT adoptions at the firm level: ICT adoptions are better facilitated when a firm has human capital, when it engages in more innovative activities, and when its organizational structure is better suited to new technologies. In addition, positive correlations between the key determinants and ICT adoptions are pronounced more for small and medium-sized firms than for large firms. Also, consistent with previous studies of technology diffusion, positive and statistically significant spillover effects are confirmed among the Colombian manufacturing firms. Considering that the existing studies in the literature of the ICT adoption focused on developed countries, it is of crucial significance to policymakers that spillover effects are empirically confirmed in a developing like Colombia where its ICT industry is still in its incipient stages and its manufacturing sector is largely consisting of small or medium-sized firms.

Although we have not delved into geographic patterns in ICT adoptions, a firm's ICT adoptions may be associated to an important extent with factors like the population density or average household income of its location. As a recent research suggests, "functional regions and not countries are the natural units for economic analysis. The reason is that economic activities are not evenly distributed across space and show clear tendencies to agglomerate" (Karlsson, Maier, Trippl, Siedschlag, Owen and Murphy, 2010, p. 30). Thus public policy to incentivize firms to adopt new technologies may vary with demographic and socioeconomic conditions of their locations. The Colombian government launched in 2011 the Live Digital Plan which aims to give the country a technological leap by the deployment massification of the Internet and the development of the national digital ecosystem. Among the projects included in the Live Digital Plan are (i) expanding fiber optic network to facilitate ICT services in small and rural areas and (ii) providing financial support to develop easy-to-use ICT applications so that firms, especially

small and medium-sized firms, can use more Internet applications productively[6]. Since the implementation of the Live Digital Plan has involved the central government, local governments, and private sectors, the Live Digital Plan is indeed an opportunity for local governments to promote ICT adoptions by local manufacturing and service firms.

We believe that the implications of our findings are of the utmost importance for public policy interventions. First, most of these ICTs are still at an early stage of adoption and implementation for small and medium-sized firms in an emerging economy like Colombia. Hence the government support to the programs aimed at facilitating the adoption of ICTs should be given priority. Second, the information spillover also calls for a pro-technology government policy to enhance the network infrastructure crucial to the diffusion of ICTs such as broadband deployment. Third, the presence of a skilled labor force is found to be a significant determinant of ICT adoptions at the firm level. Although the Colombian government initiatives to increase technical knowledge and skills such as SENA programs[7] have been successful, renewed emphasis needs to be placed on training and hiring workers with advanced knowledge and skills. Lastly, export- and innovation-oriented firms are found to more likely adopt ICTs. This finding reinforces government support for R&D and globalization at the firm level, especially in an emerging economy like Colombia.

Acknowledgements

The authors are grateful to the Departamento Nacional de Estadística, DANE for providing the valuable data for this study. We also thank the two anonymous referees for their constructive and insightful comments on an earlier version of this article.

References

Aghion, P. (2002), Schumpeterian growth theory and the dynamics of income inequality, Econometrica, 70, 855–882.

Akmanligil, M., Palvia, P. (2004), "Strategies for global information systems development, Information and Management", 42, 45–59.

[6] Gutiérrez (2013) makes a review of the most salient government ICT policies directed toward the sectors of production in Colombia.

[7] Sena stands for Servicio Nacional de Aprendizaje, or National Service of Training and is a Colombian institute responsible for undertaking technical training programs since 1957.

Antonelli, C. (1989), "The role of technological innovations in mixed model of international diffusion of process innovations: the case of open-end spinning rotors", Research Policy, 18, 273–288.

Aoun, D., Hwang, J. (2008), "The effects of cash flow and size on the investment decisions of ICT firms: A dynamic approach", Information Economics and Policy, 20, 120-134.

Arvanitis, S. (2005), "Computerization, workplace organization, skilled labour and firm productivity: evidence for the Swiss business sector", Economic of Innovation and New Technology, 14, 225–249.

Baldwin, J., Sabourin, D., Smith, D. (2004), "Firm performance in the Canadian food processing sector: the interaction between ICT, advanced technology use and human resource competencies", in: OECD (Ed.), The Economic Impact of ICT: Measurement, Evidence and Implications. OECD, Paris, 153–181.

Bartelsman, E., Doms, M. (2000), "Understanding productivity: lessons from longitudinal microdata", Journal of Economic Literature, 38, 569–594.

Battisti, G. (2008) "Innovations and the economics of new technology spreading within and across users: gaps and way forward", Journal of Cleaner Production, 16S1, S22-S31.

Battisti, G., Canepa, A., Stoneman, P. (2009), "E-Business usage across and within firms in the UK: profitability, externalities and policy", Research Policy, 38, 133-143.

Battisti, G., Stoneman, P. (2010), "How Innovative are UK Firms? Evidence from the Fourth UK Community Innovation Survey on Synergies between Technological and Organizational Innovations", British Journal of Management, 21, 187–206.

Battisti, G., Hollenstein, H., Stoneman, P., Woerter, M. (2007), "Inter and intra firm diffusion of ICT in the United Kingdom (UK) and Switzerland (CH): an internationally comparative study bases on form-level data", Economics of Innovation and New Technology, 16, 669-687.

Battisti, G., Stoneman, P. (2003), "Inter and intra firm effects in the diffusion of new process technology", Research Policy, 32, 1641-1655.

Battisti, G., Stoneman, P. (2005), "The intra-firm diffusion of new process technologies", International Journal of Industrial Organization, 23, 1-22.

Bayo-Moriones, A., Lera-Lopez, F. (2007), "A firm-level analysis of determinants of ICT adoption in Spain", Technovation, 27, 352-366.

Berman, E., Bound, J., Griliches, Z. (1994), "Changes in the demand for skilled labor within U.S. manufacturing: evidence from the annual survey of manufactures", Quarterly Journal of Economics, 109, 367–397.

Bertschek, I. (1995), "Product and process innovation as a response to increasing imports and foreign direct investment", Journal of Industrial Economics, 43, 341–357.

Black, S., Lynch, L. (2004), "What's driving the new economy: the benefits of workplace innovation", Economic Journal, 114, 97-116.

Bocquet, R., Brossard, O., Sabatier, M. (2007), "Complementarities in organizational design and the diffusion of information technologies: An empirical analysis", Research Policy, 36, 367-386.

Braga, H., Willmore, L. (1991), "Technological imports and technological effort: an analysis of their determinants in Brazilian firms", Journal of Industrial Economics, 39, 421–432.

Bresnahan, T., Trajtenberg, M. (1995), "General purpose technologies: engines of growth?", Journal of Econometrics, 65, 83–108.

Bresnahan, T., Brynjolfsson, E., Hitt, L. (2002), "Information technology, workplace organization, and the demand for skilled labor: firm-level evidence", Quarterly Journal of Economics, 117, 339–376.

Bruque, S., Moyano, J. (2007), "Organisational determinants of information technology adoption and implementation in SMEs: The case of family and cooperative firms", Technovation, 27, 241-253.

Brynjolfsson, E., Hitt, L. (1996), "Paradox lost: Firm level evidence on returns to information systems spending", Management Science, 42, 541–558.

Brynjolfsson, E., Yang, S. (1996), "Information technology and productivity: a review of the literature", Advances in Computers, 43, 179–214.

Bugamelli, M., Pagano, P. (2001), "Barriers to investment in ICT", Applied Economics, 36, 2275-2286.

Caroli, E., Reenen, J. (2001), "Skill-biased organizational change? Evidence from a panel of British and French establishments", Quarterly Journal of Economics, 116, 1449–1492.

Caroli, E., Greenan, N., and Guellec, D. (2001), "Organizational change and skill accumulation", Industrial and Corporate Change, 10, 481-506.

Chapman, P., James-Moore, M., Szczygiel, M., Thompson, D. (2000), "Building internet capabilities in SMEs", Logistics Information Management, 13, 353–360.

Cohen, W., Levin, R. (1989), "Empirical studies of innovation and market structure", in: Schmalensee, R., Willig, R. (Eds.), Handbook of Industrial Organization, Vol. II, North Holland, Amsterdam, pp. 1059–1107.

Cohen, W., Levinthal, D. (1989), "Innovation and learning: the two faces of R&D", Economic Journal, 99, 569–596.

Cohen, W., Levinthal, D. (1990), "Absorptive Capacity: A New Perspective on Learning and Innovation", Administrative Science Quarterly, 35, 128-152.

Colombo, M., Mosconi, R. (1995), "Complementarity and cumulative learning effects in the early diffusion of multiple technologies", Journal of Industrial Economics, 63, 13-48.

Commander, S., Harrison, R., Menezes-Filho, N. (2011), "ICT and productivity in developing countries: New firm-level evidence from Brazil and India." Review of Economics and Statistics, 93, 528–541.

Corrocher, N., Fontana, R. (2008), "Objectives, obstacles and drivers of ICT adoption: What do IT managers perceive?", Information Economics and Policy, 20, 229–242.

David, P., Wright, G. (1999), Early twentieth century productivity growth dynamics: an inquiry into the economic history of 'our ignorance.' SIEPR Discussion Paper, No. 98-3, Stanford Institute of Economic Policy Research, Stanford University, Stanford, CA, U.S.A.

Dutta, S., Lanvin, B., Paua, F. (Eds.) (2003). The Global Information Report 2002–03: Readiness for the Networked World. Oxford University Press: New York and Oxford.

Fabiani, S., Schivardi, F., Trento, S. (2005), "ICT adoption in Italian manufacturing: firm-level evidence", Industrial and Corporate Change, 14, 225–249.

Falk, M. (2005), "ICT-linked firm reorganization and productivity gains", Technovation, 25, 1229–1250.

Filmer, D. Pritchett, L. (2001), "Estimating Wealth Effects Without Expenditure Data—Or Tears: An Application To Educational Enrollments In States Of India," *Demography*, 38, 115-132,

Galliano, D., Roux, P., Filippi, M. (2001), "Organizational and spatial determinants of ICT adoption: the case of French industrial firms", Environment and Planning, 33, 1643–1663.

Gattignon, H., Robertson, T. (1989), "Technology diffusion: an empirical test of competitive effects", Journal of Marketing, 53, 35–49.

Geroski, P. (2000), "Models of technology diffusion", Research Policy, 29, 603–625.

Giuri, P., Torrisi, S., Zinovyeva, N. (2008), "ICT, skills, and organizational change: evidence from Italian manufacturing firms", Industrial and Corporate Change, 17, 29–64.

Gretton, P., Gali, J., Parham, D. (2004), "The effects of ICTs and complementary innovations on Australian productivity growth", in: OECD (Ed.), The Economic Impact of ICT: Measurement, Evidence and Implications, OECD, Paris, 105–130.

Griliches, Z. (1957), "Hybrid corn: an exploration in the economics of technological change", Econometrica, 48, 501–522.

Guadalupe, M., Kuzmina, O., Thomas, C. (2012), "Innovation and Foreign Ownership", American Economic Review, 102, 3594–3627.

Gutiérrez, Luis (2011), " ICT and labor productivity in Colombian manufacturing industry". In Balboni, M., Rovira, S., and Vergara, S. (Eds.), ICT in Latin America. A microdata analysis, ECLAC, pp. 121-144.

Gutiérrez, Luis (2013), "TIC y sector productivo en Colombia". In Rovira, S. and Stumpo, G. (Eds.), Entre Mitos y Realidades: TIC, Políticas Públicas y Desarrollo Productivo en América Latina, CEPAL, pp. 195-224.

Haller, S., Siedschlag, I. (2011), Determinants of ICT adoption: evidence from firm-level data. Applied Economics, 43, 3775–3788.

Hollenstein, H. (2004), "Determinants of the adoption of information and communication technologies (ICT): An empirical analysis based on firm-level data for the Swiss business sector", Structural Change and Economic Dynamics, 15, 315-342.

Hollenstein, H., Woerter, M. (2008), "Inter and intra-firm diffusion of technology: the example of E-commerce. An analysis based on Swiss firm-level data", Research Policy, 37, 545-564.

Humphrey, J., Mansell, R., Pare, D., Schmitz, H. (2003), "The reality of E-commerce with developing countries", A report prepared for the Department for International Development's Globalisation & Poverty Programme jointly by the London School of Economics and the Institute of Development Studies, Sussex, London/Falmer, March.

Indjikian, R., Siegel, D. (2005), "The Impact of investment in IT on economic performance: implications for developing countries", World Development, 33, 681–700.

Jorgenson, D., Stiroh, K. (2000), "Raising the speed limit: US economic growth in the information age", Brookings Papers on Economic Activity, 31, 125-236.

Karlsson, C., Maier, G., Trippl M., Siedschlag, U., Owen, R. and Murphy, G. (2010), "ICT and Regional Economic Dynamics: A Literature Review" JRC Scientific and Technical Report.

Karshenas, M., Stoneman, p. (1993), "Rank, stock order and epidemic effects in the diffusion of new process technologies: an empirical model", Rand Journal of Economics, 24, 503–528.

Kowtha, N., Choon, T. (2001), "Determinants of website development: a study of electronic commerce in Singapore", Information and Management, 39, 227–242.

Kumar, N., Saqib, N. (1996), "Firm size, opportunities for adaptation and in-house R&D activity in developing countries: the case of Indian manufacturing", Research Policy 25, 713–722.

Lal, K. (2004), "E-business and export behavior: Evidence from Indian firms", World Development, 32, 505-517.

Lai, V., Guynes, J. (1997), "An assessment of the influence of organizational characteristics on information technology adoption decision: a discriminative approach", IEEE Transactions on Engineering Management, 44, 146–157.

Lucchetti, R., Sterlacchini, A. (2004), "The adoption of ICT among SMEs: evidence from an Italian survey", Small Business Economics, 23, 151–168.

Mansfield, E. (1961), "Technological change and the rate of imitation". Econometrica, 29, 741–766.

Mansfield E. (1963), "The speed of response of firms to new techniques", Quarterly Journal of Economics, 77, 290-309.

Mansfield, E. (1989), "The diffusion of industrial robots in Japan and United States", Research Policy, 18, 183–192.

McGuckin, R., Stiroh, K. (2002), "Computers and productivity: Are aggregation effects important?", Economic Inquiry, 40, 42-59.

Milgrom, P., Roberts, J. (1990), "The economics of modern manufacturing", American Economic Review, 80, 511–528.

Milgrom, P., Roberts, J. (1990), "Complementarities and fit Strategy, structure, and organizational change in manufacturing, Journal of Accounting and Economics, 19, 179 - 208.

Ministerio de Comunicaciones (2008), Plan Nacional de Tecnologías de la Información y las Comunicaciones, Colombia.

Ministerio del Poder Popular para Ciencia, Tecnología e Industrias Intermedias (2007), Plan Nacional de Telecomunicaciones, Informática y Servicios Postales – PNTIySP 2007-2013, Venezuela.

Moodley, S. (2002), "Competing in the digital economy? The dynamics and impact of B2B E-commerce on the South African manufacturing sector", WIDER Discussion Paper, No. 79.

Morikawa, M. (2004), "Information technology and the performance of Japanese SMEs", Small Business Economics, 23, 171–177.

Morrison, C., Siegel, D. (1997), "External capital factors and increasing returns in US manufacturing", The Review of Economics and Statistics, 79, 647–654.

Parente, S. (1994), "Technology adoption, learning-by-doing, and economic growth", Journal of Economic Theory, 63, 346–369.

Perez, M., Martınez, A., de Luis, P., Vela, M. (2005), "The differences of firm resources and the adoption of teleworking", Technovation, 25, 1476–1483.

Premkumar, G., Roberts, M. (1999), "Adoption of new information technologies in rural small business", OMEGA - International Journal of Management Science, 27, 467–484.

Siegel, D. (1997), "The impact of computers on manufacturing productivity growth: A multiple-indicators, multiple-causes approach", The Review of Economics and Statistics, 79, 68–78.

Simon, J, (2011) The ICT Landscape in BRICS Countries: Brazil, India, China. European Commission Joint Research Centre Institute for Prospective Technological Studies.

Stieglitz, N., Heine, K., (2007), "Innovations and the role of complementarities in a strategic theory of the firm", Strategic Management Journal, 28, 1–15.

Stiroh, K. (2001), "What drives productivity growth?", FRBNY Economic Policy Review, 16, 37–59.

Swamidass, P. (2003), "Modeling the adoption rates of manufacturing technology innovations by small US manufacturers: a longitudinal investigation", Research Policy, 32, 351–366.

Teo, T., Pian, Y. (2003), "A contingency perspective on Internet adoption and competitive advantage", European Journal of Information Systems, 12, 78–92.

Udo, G., Edoho, F. (2000), "Information technology transfer to African nations: An economic development mandate", Journal of Technology Transfer, 25, 329–342.

Westphal, J., Gulati, R., Shortell, S. (1997), "Customization or conformity? An institutional and network perspective on the content and consequences of TQM adoption", Administrative Science Quarterly, 42, 366–394.

Williams, L. (1994), "Understanding distribution channels: an inter-organizational study of EDI adoption", Journal of Business Logistics, 15, 173–203.

Yap, C., Soh, C., Raman, K. (1992), "Information systems success factors in small businesses", OMEGA - International Journal of Management Science, 20, 597–609.

Wooldridge, J.M. (2005), *Econometric analysis of cross-section and panel data.* Cambridge, Massachusetts, MIT Press.