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ECONOMY: EVIDENCE FROM THE COLOMBIAN  
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# **A Firm-Level Analysis of ICT Adoption in an Emerging Economy: Evidence from the Colombian Manufacturing Industries**

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## **Abstract**

This study examines ICT adoption among 3,759 Colombian manufacturing firms, and attempts to identify the factors that are conducive to the adoption and usage of ICT at the firm level. Our major findings are (i) that the adoption of a given information and communication technology is better facilitated when a firm is relatively large, has large human capital, engages in more innovative activities, and when a firm's organizational structure is better aligned with the given technology; (ii) that positive associations between the key determinants and ICT adoptions are more pronounced for small and medium-sized firms than for large ones, and (iii) that information spillovers within industries is also a determinant of ICT adoptions by the firms.

Keywords: ICT adoption, Internet, Innovation, Organizational change

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## **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, another important conception has been developed in the literature on technological changes: increasing recognition of 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 adoption rates across firms of ICTs (Bocquet et al., 2007; Bayo-Moriones and Lera-Lopez, 2007; Fabiani et al., 2005; Giuri et al., 2008; Hollenstein, 2004; Lucchetti and Sterlacchini, 2004).

The complementarity view, which was missing in the traditional technology diffusion literature, signifies that developing a better understanding of the complementary factors that may facilitate or retard the process of a firm's ICT adoption is an issue of contemporary importance to both managers and policy makers. First, a firm's technological choices are more likely to come to fruition when they are aligned with its operational and organizational readiness for new technologies. Hence it is necessary that managers' efforts to maximize the effectiveness of ICT adoption and usage be concomitant with their organizations' capacity to accommodate to new technologies. Second, the complementarity view may help policy makers gain new insights into the designing industrial policy to promote the usage of new technologies. For instance, firms across different industries face different business environments in terms of market competitiveness and uncertainty so that their incentive to adopt ICT may be influenced by the extent to which industrial policy reflects and conforms to distinct circumstances of their respective industries. Third, the study of complementary factors to boost ICT investments may have some macroeconomic implications as well. There is now quite conclusive evidence of a strong positive correlation between ICT investments and economic performance (Jorgenson and

Stiroh, 2000; Stiroh, 2001). 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 emerging economies, for the following reasons. First, an increasing number of emerging economies have been initiating 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, observed positive impacts on economic performance of ICT in developed countries may signify the importance to emerging economies of investments in ICT as one of the core elements in transition to the knowledge-based economy. Although deficiency in ICT investment with relatively high social opportunity costs is a typical of many emerging and transition countries, 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).

This study examines ICT adoption among 3,759 Colombian manufacturing firms, and attempts to identify the factors that are conducive to the adoption and usage of ICT at the firm level. In order to achieve this goal, we use two different data sources from the Colombian Bureau of Statistics (Departamento Nacional de Estadística - DANE): the Colombian Manufacturing Survey (Encuesta Anual Manufacturera - EAM) and the Colombian Innovation Survey II and III (Encuesta de Innovación y Desarrollo Tecnológico - EDIT). Basic ICT-related quantitative observations were collected from the 2006 EAM such as PCs per employee, ICT expenditure per employee, the usage of Internet and its business applications, the size of workforce and its composition along with different level of skills and education, and so on. In addition, observations on firms' internal characteristics such as product innovation and ICT-related organizational changes were compiled from the 2003-2004 EDIT II. Drawing on such a large database, we first construct a number of indicators that are representative of Colombian manufacturing firms across industries, geographical areas, and sizes. With different 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 spillovers 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 is relatively large, a firm has large human capital, a firm engages more innovative activities, and when a firm's organizational structure is more aligned with the given technology; (ii) that positive associations between the key determinants and ICT adoptions are more pronounced for small and medium-sized firms than for large ones, and (iii) that information spillovers within industries is also a determinant of ICT adoptions by the firms.

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. The data and the empirical specification are discussed in Section 3 followed by the empirical results in Section 4. Finally, concluding remarks are provided in Section 5.

## **2. Empirical background and theoretical framework**

As mentioned in the introduction, the literature on the adoption of ICT has documented a vast amount of empirical evidence of various factors that are inherent to a firm's ICT adoption. Although underlying determinants of a firm's decision to adopt ICT vary across different studies from firm-specific structural characteristics to competitive strategies to industrial or market environment, a general conceptual framework developed from country-specific case studies has focused mainly on the variables in the following five categories: a firm's structural characteristics, human capital, internal organizational characteristics, the characteristics of industrial environment, and the effects of ICT information spillovers. In this section, we provide a brief overview of the literature with emphasis on primary factors of firms' ICT adoption decisions that have been debated and tested in the recent empirical studies.

### *2.1 Structural characteristics of firms*

One of the most commonly tested hypotheses in the literature is that a firm's size 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 through 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, the main findings in the literature are in support of a positive correlation between the ICT adoption and the size of firms (Delone, 1981; Gretton et al., 2004; Kowtha and Choon, 2001; Lucchetti and Sterlacchini, 2004; Morikawa, 2004).

In addition to the size of firms, some studies in the literature focus 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).

## *2.2 Human capital*

Another important implication of ICT adoption at the firm level is that the implementation of new technologies is potentially influenced by individual characteristics of employees such as educational attainment and age. 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. 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; Black and Lynch, 2000;

Bresnahan et al., 2002; Chapman et al., 2000; Fabiani et al., 2005; Lucchetti and Sterlacchini, 2004; Parente, 1994; Perez et al., 2005; Yap et al., 1992).

While many studies in the literature have used the educational attainment of workers as a proxy for human capital for a firm, a few studies have examined the impact on the ICT adoption of the socio-demographic characteristics of workforce such as age. The presumption is that the inertia of old workforce may become a barrier to ICT adoption because old and more established workforce is often less adaptable and resistant to new changes that often require new skills (Bayo-Moriones and Lera-Lopez, 2007). However the empirical findings on the significance of the impact on ICT adoption of the age composition of workforce are not unambiguous (Beatty et al., 2001; Maliranta and Rouvinen, 2004).

### *2.3 Internal organizational structure*

Another principal focus of the literature related to ICT adoption has been on the complementary relationship between the adoption of ICT and firms' organizational characteristics. 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 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 delayed organizational structure allows for increased information sharing and more effective involvement in decision making among employees (Bayo-Moriones and Lera-Lopez, 2007; Black and Lynch, 2000; 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. However, empirical findings are mixed and controversial across different studies.

### *2.4 Industrial environment*

A firm's incentive to adopt ICT may also be affected by the local industrial or market structure. 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 for consideration in ICT investments. 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, Bayo-Moriones and Lera-Loez (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-Moriones and Lera-Loez, 2007; Bertschek, 1995; Gattington and Robertson, 1989; 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-Moriones and Lera-Loez (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.

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).



## *2.5 Epidemic effects (information spillovers)*

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: the frequency of contacts between current ICT adopters and potential users increases and 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 spillovers (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).

## **3. Data, variables and descriptive statistics**

### *3.1 Data*

Our empirical analysis uses two sources of data. As mentioned previously, 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 20 employees and more. The number of firms included in the manufacturing survey was about 5497 out of 7639 establishments for the year 2006. The database for this study is therefore statistically significant and very representative of 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 the data of only a subset of them, which are important in our analysis. The EAM comprises quantitative variables on production, sales, number of employees, capital stock, 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 a special annex requesting information on ICTs comprising

access and usage of ICTs by employees, adoption of network technologies, and use of the ICT network for business activities. As shown in Table 1, 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 of firms are located in Bogotá and the so-called Coffee zone.

<PLACE TABLE 1 HERE>

The second source of information is the Colombian Innovation Survey II (Encuesta de Innovación y Desarrollo Tecnológico - EDIT) also carried out by the DANE. The EDIT II requested information for the years 2003 and 2004 about innovation inputs and outputs, human capital, and organizational features. Matching the two surveys using the key provided by the DANE, we excluded (i) firms with missing values of main variables in any of the surveys, i.e., the EDIT and the EAM, (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 20 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.

Table 1 also shows a couple of notable observations on the statistics. First, a high degree of heterogeneity has been observed in all ICT indicators across manufacturing sectors 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, for instance, by Bayo-Moriones and Lera-Lopez (2007). This observation certainly provides a rationale for the study on the key determinants of ICT adoption by Colombian manufacturing firms.

### *3.2 Variables and descriptive statistics*

#### *3.2.1 ICT variables*

The ICT annex of the EAM provides a rich set of ICT indicators as reported in Table 2. We grouped these indicators in three broad intertwined categories as follows: (i) ICTs that increase an employee's productivity, (ii) ICTs that enhance the business performance of a firm as a whole, and (iii) ICTs that improve a firm's connectedness with other businesses and customers.

The first group of indicators refers to the access to and usage of basic ICTs by a firm's employees. One of such indicators is the number of PCs per worker, denoted by *PCs per employee*. A couple of interesting observations are made from Table 1. First, the mean number of PCs per worker varies substantially across different segments of the Colombian manufacturing sectors. Second, the standard deviation of the variable for small firms is large relative to those for medium and large ones. Another ICT indicator in the first group is the firm's annual expenditure per employee in hardware and software, denoted by *ICT expenditure per employee*. The ICT expenditure per employee varies substantially with the size of firms. For instance in Table 1, the ICT expenditure per employee in 2006 averaged \$57 for large firms compared with only \$19 for small ones. It is also worth noting that the standard deviation of the variable is large relative to its mean value for the firms of all sizes. Especially for medium-sized firms, its standard deviation is nearly nine times the mean value.

In addition to the number of PCs per worker, the percentage of employees who use PCs specifically for their routine tasks is examined in this study, because PCs may not be required for all employees to perform their regular tasks. Thus this variable, denoted by *workers with PCs*, is expected to provide us additional insight on the determinants of the ICT adoption. Table 1 indicates that the percentages of employees using PCs on average increases as the size of the firm increases.

The last per-employee ICT indicator of the first group is the percentage of employees who use PCs connected to the Internet, denoted by *workers connected to 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.

The second group of ICT indicators, called the business-performance-enhancing ICT indicators, consists of two dummy variables: (i) whether a firm has access to the Internet, denoted by *d\_Internet*, and (ii) whether a firm has its own registered website, denoted by *d\_webpage*. Each binary variable takes the value of one if the firm has the underlying technology and zero otherwise. Table 1 shows that the percentage of the firms with either the Internet access or own registered websites increases as the firm size increases.

The third group of ICT indicators consists of three ICT indicators that refer to a firm's degree of connectedness with the outside such as other businesses and customers. The first ICT

indicator of the third group, denoted by *d\_Internet areas*, measures the number of functional areas of a firm's business where the Internet is used. 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 the value of three. The greater the value of the variable for a firm, the higher is the degree of intra-firm diffusion of the Internet technology.

The second ICT indicator of the third group, *Internet applications*, measures the number of a firm's responses 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 the value of one if the firm responds "yes" and zero otherwise. Therefore this composite indicator takes a value between zero and five.

The last ICT indicator of a firm's connectedness with other businesses and customers is also a composite one and denoted by *networks*. This variable adds up three binary responses to the following questions whether a firm has (i) Intranet, (ii) Extranet, and (iii) LAN. For a firm's positive response to each question, the variable takes the value of one and zero otherwise. Thus, if a firm has all three forms of networks, the variable *networks* will take the value of three. Table 1 shows the larger a firm is, the higher is the degree of its connectedness with other businesses and customers.

Another important aspect of the ICT adoption by the firm that has been extensively examined in the literature is the information spillovers 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 of the epidemic effect by calculating the average of each ICT indicator across the manufacturing sector to which the firm is affiliated to as follows:

$$\bar{Y}_j = \frac{\sum_{i \neq k=1}^{N-1} Y_j^k}{N_j}$$

In the indicator above,  $Y$  refers to one of the nine ICT technologies aforementioned and  $j$  indicates the manufacturing sector to which a firm  $i$  belongs. 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. Thus, for the given technology  $Y$ , the epidemic effect in sector  $j$  is proxied by the sector-specific level of diffusion of the technology relative to firm  $i$ . This variable is included in all regressions as an additional explanatory variable for the adoption of an ICT by firms.

### 3.2.2 Organizational technologies

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) Kaizen, (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 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. Based on this reasoning, this study utilizes the EDIT II survey results for the year 2004. About 31.5% of the sample firms invested at least in one of the five technologies mentioned above.

As shown in Table 3, pair-wise correlation coefficients across the nine ICT indicators are fairly low unless it is a correlation between a pair of closely-related ICT indicators. For instance, the dummy variable  $d\_Internet$  is highly correlated with both the categorical variable  $d\_Internet\ areas$  and with  $d\_webpage$ . Finally, all correlations were statistically significant.

### 3.2.3 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 derive benefits from the technologies is potentially limited by its human capital. In this study we employed two measures of human capital at the firm level: the percentage of workers with a university degree or higher and the ratio of number of technicians to total employees. For the sample firms included in this study, the percentage of workers with higher education averages 14.2% and the percentage of total employees that are technicians is 16%.

#### *3.2.4 Other control variables*

In addition to the explanatory variables associated with a firm's organizational technologies and human capital, we incorporate in our analysis 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 control for a firm's size and multinational (foreign) ownership. First, the size of a firm is proxied by the logarithm of sales. Among our sample firms, small firms accounted for about 32.5%, medium-sized firms about 42.4%, and large firms about 25.1%. The number of the sample firms in our study and its distribution across size, regions and manufacturing activities make this study especially pertinent to the study of the ICT adoption by small and medium-sized enterprises (SMEs). Second, the presence of foreign ownership is controlled for by a binary variable which takes the value of one if foreign capital accounts for at least one percent of a firm's total ownership. The firms with at least one percent foreign ownership accounted for 31% of the sample firms.

As for the industrial environment in which a firm operates, we control for the global aspect of industrial environment 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. 6.2% of the sample firms in our study derived part of their sales revenue from the export sales.

Building upon the presumption that the adoption and use of ICTs is better facilitated when a firm is more product-innovation-oriented, we control for a binary variable which equals to one if a firm performed either product or process innovation during the year 2004 and zero

otherwise. 63% of the sample firms had some form of product or process-related innovation activity during the year 2004.

Finally, we included a set of dummy variables for five broad Colombian regions as well as for three sectors of activities of a firm. 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 four states, the Central region composed of six states, and Bogota, the capital of the country. The three sectors of activities of a firm are identified according to the OECD low, medium-low and medium-high technology aggregations of manufacturing based on SITC Rev. 3<sup>1</sup>.

#### 4. Empirical strategy

Based on the recent development in theories and empirical evidence in the literature of the ICT adoption, the following empirical specification is fitted for each of the nine ICT variables ( $Y$ ) as follows:

$$Y_{i,j} = \alpha X_{i,j} + \beta \bar{Y}_j^{-i} + \gamma ORG_{i,j} + \nu HC_i + \lambda CR4_k + \delta INNO_{i,j} + \theta TECH_{i,j} + \eta REG_i + \varepsilon_i$$

In the model above,  $i$  refers to a firm and  $j$  denotes the manufacturing sector to which the firm is affiliated.  $X$  is a vector of three control variables: the logarithm of a firm's sales, a firm's exports as a percentage of its total sales, and the presence of foreign ownership.  $\bar{Y}_j^{-i}$  is the spillover effect of the ICT diffusion within the manufacturing sector  $j$  where the firm  $i$  belongs. The binary variable  $ORG$  indicates whether a firm invested at least in one of the five technologies of organizational tools.  $HC$  is a set of two human capital-related measures: the percentage of workers with a university degree or higher and the ratio of number of technicians to total employees.  $CR4$ , the four-firm concentration ratio, measures the share of total output accounted for by the four largest firms in the manufacturing sector  $j$  where the firm  $i$  is affiliated. The binary variable  $INNO$  indicates if a firm performed either product or process innovation during the year 2004.  $TECH$  is a set of three dummy variables, each of which refers to whether the firm  $i$  is located in medium-high, medium-low or low technological sector. Finally, the variable  $REG$

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<sup>1</sup> See OECD (1999). SITC Rev. 3 stands for standard international trade classification. The OECD classifies industries based on technological intensity and proposes four groups. We end up with only three groups since we believe there are no high technology manufacturing sectors in Colombia.

is a set of dummies that control for the location of the firm  $i$  among the five broad Colombian regions.

Given the cross-sectional nature of our data set and the three different types of our dependent variables, the following three econometric techniques are used to explain the ICT adoption by Colombian manufacturing firms. First, the ordinary least squares (OLS) method is used for the first group of quantitative ICT indicators which are directly related to workers' productivity. Second, probit regression is used for the binary variables for a firm's Internet access and its own registered website. Last, the ordered probit regression estimation is employed for the analysis of the three categorical indicators of firm's connectedness with other businesses and customers. All estimates are robust standard errors clustered by Colombian industrial sectors. All estimation results are reported first for the entire sample firms and then for the two sub-samples: large firms only and small and medium-sized firms.

#### *4.1 ICTs related to employees' performance*

Table 4 presents estimation results for each of the four measures of ICTs that we claim directly affect the performance of a firm's workers. Consistent with the empirical findings in previous country-specific studies (for example, Fabiani et al., 2005 and Haller and Siedschlag, 2008) as well as the theoretical analysis of Cohen and Levinthal (1989), human capital variables are found to be the most significant factors in the adoption of PCs by a firm. First, the percentage of workers with a university degree or higher is highly and positively associated with all of the four ICT indicators in the first group: the number of PCs per worker, a firm's annual expenditure per employee in hardware and software, the percentage of employees who use PCs specifically for their routine tasks, and the percentage of employees who use PCs connected to the Internet.

Second, the other measure of human capital, the ratio of number of technicians to total employees, is found to be positively related to the three ICT indicators except for a firm's annual expenditure per employee in hardware and software. This finding highlights the importance in the ICT adoptions of strengthening human capital within firms and is consistent with the notion of absorptive capacity of Cohen and Levinthal (1990): "the prior related knowledge to assimilate and use new knowledge."

<PLACE TABLE 4 HERE>



A second factor that facilitates the use of PCs and the Internet is firm size, proxied by the logarithm of a firm's sales. The firm size is found to be highly and positively associated with all four ICT indicators in the first group. A firm's previous efforts to achieve product or process innovation as well as the implementation of some organizational changes within the firm are also found to be effective determinants of a firm's adoption of the ICTs that enhance workers' performance.

For the entire sample firms, the presence of foreign capital in a firm's ownership also facilitates the adoption of ICTs. It is found that a firm with a relative high ratio of exports to sales is likely to have more workers directly connected to the Internet. However, the technological level of a particular manufacturing sector to which a firm belongs does not appear to have any influence in the firm's adoption of these ICTs. The concentration ratio of the four largest firms in a manufacturing sector is found to be negatively related to all firm's ICT adoptions although it is marginally statistically significant only for the indicator of workers connected to the Internet.

Last, as shown in Table 4, positive epidemic effects are confirmed, 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. Its significance is more pronounced not only by the positive sign but also the magnitude of estimated coefficient across all dependent variables.

Table 5 shows the estimation results first for large sample firms only and then for small and medium-sized firms, respectively. The main idea behind splitting the data set into two sample groups is to see whether the explanatory power of each control variable distinctively varies with the size of firms. It appears that the level of education in a firm's workforce and its efforts to align organizational changes with the ICTs are all positively associated with the adoption of these ICTs regardless the size of the firm. Last, the overall information spillover effects seem to be more pronounced for small and medium-sized firms than for large ones.

<PLACE TABLE 5 HERE>

In a nut shell, our empirical findings suggest that the adoption of an ICT is better facilitated not only when a firm is larger with more human capital and modern organizational structure but also when a firm is more innovation-oriented and belongs to a manufacturing sector with a relatively high diffusion rate of the given ITC.

#### *4.2 ICTs that enhance business performance*

In Section 3, we identified and discussed the two business-performance-enhancing ICT indicators: whether a firm has access to the Internet and whether a firm has its own registered website (see Table 2). As expected (see Table 6), a firm's ICT-absorptive capacity, proxied by the two human capital measures, is positively associated with the firm's use of the Internet and webpage. A firm's ratio of exports to sales is found to be of equal importance in a firm's use of the Internet. This finding is consistent with the presumption that a firm competing in international markets has a stronger incentive to use the Internet to stay globally connected. The estimation results also confirm that a firm that implemented technology-complementary organizational changes or engaged in product or process innovation is more likely to adopt the both types of ICTs.

<PLACE TABLE 6 HERE>

When the same empirical specifications are fitted in two different sample groups, the estimation results for small and medium-sized firms in Table 7 are largely consistent with the ones for the entire sample firms in Table 6. However, the estimation results for large sample firms substantially depart from the previous findings. As evidenced in Table 7, most of the explanatory variables are found not significant in the adoption of the Internet and webpage by large firms. One possible explanation to this contrary finding is that, unlike large firms for which the underlying technologies have been adopted for a long while and become mature technologies, small and medium-sized firms may still face more hurdles such as opportunity costs of investments in human capital, innovations, and technology-complementary organizational changes.

<PLACE TABLE 7 HERE>

#### 4.3 ICT connectedness of firms

We previously defined three ICT indicators that measure a firm's degree of connectedness not only within but also with the outside such as other businesses and customers: the number of functional areas of a firm's business where the Internet is used (*d\_ Internet areas*), the number of specific Internet applications that a firm uses (*Internet applications*), and the number of the types of the network structure that a firm employs (*networks*). As discussed in Section 3, the three ICT indicators are categorical in the sense that each dependent variable takes a larger value as a firm responds "yes" to more categorical questions. As summarized in Table 8, we have found that a firm's degree of connectedness is increasing when the firm's workforce is more educated, the firm engages more in innovation-related activities, the firm has implemented organizational changes that are complementary for the ICTs, the firm competes in international markets, and when the firm is relatively large. The epidemic effects are also found to be positively associated with the adoption of these network technologies, suggesting that the likelihood that a firm learns about a new technology and adopts it increases as more firms within the industry adopt the technology.

<PLACE TABLE 8 HERE>

Similar to our empirical findings in the ICTs that enhance business performance in Section 4.2, some explanatory variables are found not significant when the estimation is fitted only for large firms (see Table 9). We believe this finding can be attributed to the following two reasons. First, this study utilizes a cross-sectional data set so that this study has its limitations in explaining the ICT adoption processes when a large firm adopted the underlying network-related technologies earlier. Second, those network-related technologies have not yet become mature for small and medium-sized firms so that many of the explanatory variables such as human capital and organizational changes may be more relevant to the ICT adoption processes of small and medium-sized firms.

<PLACE TABLE 9 HERE>

## **5. 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 representative in terms of their size, regional location, and manufacturing sectors they are affiliated to.

We find robust and persistent empirical evidence that helps us understand the key determinants in the ICT adoption at the firm level. Our main findings summarized in Table 4 suggest that the adoption of a given technology is better facilitated when a firm is relatively large, a firm has large human capital, a firm engages more innovative activities, and when a firm's organizational structure is more aligned with the given technology. It is also worth noting that positive associations between these key determinants and ICT adoptions are more pronounced for small and medium-sized, which account for about two-thirds of the sample firms. Furthermore, consistent with the previous studies of technology diffusion, significant and positive epidemic effects are empirically confirmed.

We believe the implications of these 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 through the programs aimed at facilitating the adoption of those ICTs should be given priority. Second, the information spillovers call also for a pro-technology government policy to enhance the network infrastructure such as broadband deployment crucial to the diffusion of ICTs. Third, the presence of a skilled labor force is found to be one of the most significant determinants of a firm's ICT adoption. It is desired that public policy be oriented toward public training programs in ICTs for the current workforce as well as providing basic ICT skills in primary and secondary schooling. Lastly, firms that are export and innovation-oriented are found to be early ICT adopters among the Colombian manufacturing firms. This finding provides further evidence that an emerging economy like Colombia needs public support to spur R&D and globalization of its economy.

<PLACE TABLE 10 HERE>

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Table 1  
Descriptive statistics

	PCs per employee	ICT expenditure per worker (USD)*	LF_PC	Internet	LF_connected	Webpage	Internet areas	Networks	Internet applications
<b>SIZE</b>									
20-50	1253.0	1,304	1253	1253	1253	1483	1483	1253	1483
	15.3%	19	24	81.1%	34.2	23.7%	1.136	0.770	1.399
	0.942	91	24.0	0.4	37.1	0.4	1.0	0.6	1.5
51-200	1778.0	1,764	1778	1778	1778	1936	1936	1778	1936
	13.8%	39	28	94.3%	45.5	48.0%	1.786	1.037	2.095
	0.402	312	24.4	0.2	38.4	0.5	1.0	0.6	1.5
> 200	1105.0	1,038	1105	1105	1105	1142	1142	1105	1142
	12.7%	57	33	98.8%	49.7	75.2%	2.384	1.519	2.571
	0.120	156	25.9	0.1	34.9	0.4	0.9	0.8	1.4
<b>MANUFACTURING SECTOR</b>									
Food and Tobacco	973.0	952	973	973	973	1079	1079	973	1079
	35.5	3,555	24.072	0.829	32.700	0.319	1.465	0.987	1.570
	129.9	238	22.6	0.4	35.0	0.5	1.1	0.7	1.5
Textiles and leather	925.0	948	925	925	925	1101	1101	925	1101
	17.4	22,522	21.579	0.839	40.565	0.326	1.311	0.883	1.503
	41.5	12,820	23.8	0.4	39.7	0.5	1.1	0.6	1.5
Wood, paper and printing	544.0	543	544	544	544	626	626	544	626
	36.5	4,293	36.239	0.912	45.819	0.390	1.679	1.035	2.006
	128.3	13,442	29.0	0.3	36.9	0.5	1.1	0.6	1.6
Petroleum and Chemicals	854.0	856	854	854	854	921	921	854	921
	40.8	62	34.358	0.936	47.303	0.539	1.876	1.178	2.180
	183.3	452	26.6	0.2	37.3	0.5	1.1	0.7	1.5
Non-metallic mineral products	253.0	242	253	253	253	269	269	253	269
	24.2	25	26.534	0.893	40.980	0.476	1.729	1.134	1.803
	63.1	61	27.9	0.3	38.7	0.5	1.1	0.8	1.5
Steel products and Machines	698.0	698	698	698	698	778	778	698	778
	16.3	34	23.795	0.865	40.224	0.432	1.504	0.936	1.801
	39.8	148	22.3	0.3	37.6	0.5	1.1	0.6	1.6
Electrical equipment and other machinery and equipment n.e.c	169.0	172	169	169	169	182	182	169	182
	24.9	48	32.580	0.893	48.124	0.588	1.912	1.065	2.275
	46.5	154	23.8	0.3	37.9	0.5	1.2	0.7	1.7
Motor vehicles, and other transport equipment	143.0	145	143	143	143	160	160	143	160
	34.3	28	26.133	0.825	39.161	0.400	1.450	0.965	1.681
	95.7	68	25.4	0.4	38.4	0.5	1.1	0.7	1.6
Furniture	351.0	351	351	351	351	381	381	351	381
	11.5	15	22.074	0.846	37.595	0.475	1.475	0.877	1.785
	19.0	31	21.7	0.4	38.3	0.5	1.1	0.6	1.5

Note: In each column the first row is number of firms, the second one is the mean and the last one is the standard deviation.

\*An exchange rate of \$2261.5 was used.

Table 1 (continued)  
Descriptive statistics

	PCs per employee	ICT expenditure per worker (USD)*	LF_PC	Internet	LF_connected	Webpage	Internet areas	Networks	Internet applications
REGION									
North-Caribbean	419.0	394	419	419	419	444	444	419	444
	25.9	38	27.243	0.862	33.687	0.405	1.653	1.029	1.984
	55.9	353	23.8	0.3	34.1	0.5	1.1	0.7	1.6
Pacific-East	885.0	828	885	885	885	941	941	885	941
	31.2	52	28.559	0.873	37.879	0.400	1.607	1.046	1.801
	92.7	165	25.9	0.3	36.3	0.5	1.1	0.7	1.5
Coffee Zone	1343.0	1,257	1,343	1,343	1,343	1,401	1,401	1,343	1,401
	23.8	24	25.903	0.844	41.874	0.412	1.637	0.923	1.906
	67.6	86	26.23	0.36	39.56	0.49	1.11	0.71	1.58
Central, East and South-East	516.0	644	516	516	516	733	733	516	733
	38.4	38	25.998	0.816	34.587	0.304	1.173	1.023	1.277
	223.1	159	25.6	0.4	36.1	0.5	1.2	0.8	1.5
Bogotá	1716.0	1,756	1,716	1,716	1,716	1,945	1,945	1,716	1,945
	26.4	38	27.577	0.909	45.061	0.459	1.612	1.024	1.866
	105.9	319	24.5	0.3	38.0	0.5	1.1	0.6	1.6

Note: In each column the first row is number of firms, the second row is the mean and the third row is the standard deviation.

\*An exchange rate of \$2261.5 was used.

Table 2  
Description of variables

Variable	Description	Data source
ICTs that affect directly Workers performance		
PCs per employee	Number of PCs divided by number of workers	EAM 2006
log(ICT expenditure per worker in USD)	Expenditure for hardware and software of ICTs per employee	EAM 2006
Workers with PCs (%)	Percentage of employees who used PCs in their daily work	EAM 2006
Workers connected to Internet (%)	Percentage of employees with PCs who are connected to Internet	EAM 2006
ICTs that affect directly overall firm businesses		
d_Internet	Dummy variable equal to one if the firm reported to have Internet in its premises, and 0 otherwise	EAM 2006
d_webpage	Dummy variable equal to one if the firm reported to have a Webpage, and 0 otherwise	EAM 2006
Firm's Infrastructure in ICTs		
d_Internet areas	Categorical variable running from 0 to 3. It is the sum of the binary responses, each of which takes the value 1 if the firm uses Internet for: i) Management, ii) Production and iii) Sales; and 0 otherwise	EAM 2006
Networks	Categorical variable running from 0 to 3. It sums up the binary responses each of which takes the value of 1 if the firm has: i) Intranet, ii) Extranet and iii) LAN; and 0 otherwise	EAM 2006
Internet applications	Categorical variable that adds up 5 binary responses which take the value of 1 if the firm adopts the named technology: i) Ordering raw material, ii) Selling products, iii) electronic banking, iv) customer services, and v) distribute products on line ; and 0 otherwise.	EAM 2006

Source: DANE

Table 2 (continued)  
Description of variables

Variable	Description	Data source
Main Explanatory Variables		
Size	log(2006 annual sales)	EAM 2006
% College employees	Ratio of employees with university degree and higher	EAM 2006
% technical employees	Ratio of technician workers to total employees	EAM 2006
Export	Percentage of export over sales	EAM 2006
Foreign	Dummy variable equal to 1 if the firm has foreign ownership greater than 1%	EAM 2006
Innovation	Dummy variable equal to 1 if the firm reported to have had product or process innovation in 2004	EDIT II
Organizational change	Dummy variable equal to 1 if the firm reported to have performed at least one organizational change in 2004 in: i) quality management of products, ii) Kaisen, iii) TQM, iv) Enforcement of ISO norms, and v) others	EDIT II
Concentration ratio	Sum of production shares of the four greatest firms in each SIC	EAM 2006
Tech	Dummies for three sectors of activities of the firm, identified according to the OECD low, medium-low and medium- high technology aggregations of manufacturing based on NACE Rev. 2	EAM 2006
Region	Dummies for 5 regions that clusters 21 states in which a firm is located.	EAM 2006

Source: DANE

Table 3  
Overall descriptive statistics and correlation matrices

A. ICT Variables

	Mean	Std. dev.	1	2	3	4	5	6	7	8	9
1. PCs per employee	13.930	54.229	1								
2. ICT expenditure per employee	36.486	237.180	0.0584*	1							
3. Workers with PCs (%)	27.030	25.230	0.1589*	0.2320*	1						
4. Internet	0.870	0.336	0.0556*	0.2648*	0.3125*	1					
5. Workers connected to Internet (%)	40.740	37.810	0.0535*	0.1871*	0.3914*	0.4089*	1				
6. Webpage	0.410	0.492	0.0739*	0.3086*	0.2926*	0.3427*	0.2784*	1			
7. Internet Areas	1.560	1.110	0.0912*	0.3575*	0.3950*	0.6310*	0.4431*	0.5554*	1		
8. Networks	1.000	0.687	0.0848*	0.3427*	0.3251*	0.4961*	0.3043*	0.4203*	0.5364*	1	
9. Internet applications	1.790	1.550	0.0734*	0.2920*	0.2712*	0.5015*	0.3330*	0.4970*	0.6670*	0.4194*	1

\*p<0.01

B. Explanatory Variables

	Mean	Std. dev.	1	2	3	4	5	6	7
1. log of sales	14.68	1.7665	1						
2. Export	6.207	17.113	0.3046*	1					
3. Foreign	0.30774	0.46159	0.4037*	0.2402*	1				
4. Share professional	14.21	16.05	0.1047*	0.0483*	0.0713*	1			
5. Share Technicians	16.01	19.899	0.0542*		0.0450*		1		
6. Innovation 2005	63.33	48.194	0.2561*	0.0945*	-0.0851*	0.0371*		1	
7. Organizational	31.453	46.437	0.3424*	0.1057*	0.1283*	0.0791*	0.0298	0.3172*	1

\*p<0.01

Table 4  
ICT adoption affecting employees – all firms

	PCs per employee	log(ICT expenditure per worker)	Workers with PCs (%)	Workers connected to Internet (%)
log of sales	0.007*** (0.002)	0.806*** (0.084)	2.256*** (0.333)	3.107*** (0.517)
% export	0.008 (0.009)	0.331 (0.439)	3.594 (2.254)	14.779*** (3.728)
Dummy if foreign governance	0.025*** (0.008)	0.601** (0.276)	7.122*** (1.973)	1.158 (1.817)
% college employees	0.202*** (0.015)	1.956*** (0.515)	35.209*** (3.060)	23.716*** (3.668)
% technical employees	0.077*** (0.012)	0.447 (0.373)	15.444*** (2.576)	10.588*** (2.646)
Dummy innovation 2004	0.005 (0.003)	0.253* (0.136)	0.777 (0.973)	4.455*** (1.322)
Dummy Organizational change	0.011*** (0.004)	0.703*** (0.174)	3.511*** (0.860)	0.797 (1.466)
Medium high technology	-0.001 (0.006)	0.282 (0.231)	-2.291** (1.013)	0.961 (1.331)
Medium low technology	-0.006 (0.006)	0.153 (0.208)	-1.057 (0.774)	0.163 (1.448)
Caribe	-0.027 (0.021)	0.300 (0.646)	7.155*** (1.832)	1.852 (6.784)
Pacifico	-0.001 (0.022)	3.198*** (0.726)	12.639*** (1.227)	9.861 (6.578)
Cafetera	-0.006 (0.023)	0.295 (0.720)	13.191*** (1.652)	14.326** (6.189)
Central	-0.006 (0.023)	0.953 (0.690)	10.792*** (2.093)	5.485 (7.124)
Bogota	-0.000 (0.022)	0.893 (0.672)	10.761*** (1.426)	14.705** (6.059)
CR4	-0.006 (0.010)	-0.403 (0.366)	-0.984 (1.447)	-5.041* (2.637)
Spillover of PCs per employee	0.239*** (0.029)			
Spillover of ICT expenditure per worker		0.199* (0.101)		
Spillover of LF_PC			0.541*** (0.056)	
Spillover of LF_connected				0.242 (0.158)
Constant	-0.064* (0.035)	-8.226*** (1.491)	-39.924*** (4.912)	-31.894** (13.014)
Observations	3,759	3,759	3,759	3,759
R-squared	0.254	0.218	0.207	0.074

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1



Table 5  
ICT adoption affecting employees by firm size – small and medium-sized firms

	PCs per employee	log(ICT expenditure per worker)	Workers with PCs (%)	Workers connected to Internet (%)
log of sales	0.015*** (0.003)	0.902*** (0.108)	3.453*** (0.577)	5.134*** (0.957)
% export over sales	0.005 (0.011)	0.069 (0.561)	5.333** (2.605)	12.173*** (4.422)
Dummy if foreign governance	0.046*** (0.014)	1.107** (0.426)	9.706*** (2.921)	5.461* (2.946)
% college employees	0.193*** (0.018)	1.576*** (0.587)	36.658*** (3.401)	23.603*** (4.500)
% technical employees	0.073*** (0.013)	0.585 (0.367)	16.223*** (3.043)	14.772*** (3.297)
Dummy innovation 2004	0.004 (0.004)	0.234 (0.145)	0.701 (1.103)	4.114** (1.611)
Dummy Organizational change	0.014*** (0.004)	0.787*** (0.226)	4.608*** (1.142)	0.058 (1.758)
Medium high technology	-0.006 (0.006)	0.284 (0.205)	-3.730*** (1.373)	-0.884 (1.735)
Medium low technology	-0.007 (0.006)	0.067 (0.190)	-1.782 (1.317)	-0.953 (1.802)
Caribe	-0.021 (0.026)	-0.218 (0.574)	7.393** (3.093)	6.730 (6.558)
Pacifico	0.002 (0.026)	3.083*** (0.622)	13.391*** (2.372)	12.625** (6.278)
Cafetera	-0.004 (0.027)	-0.349 (0.569)	14.694*** (2.978)	17.324*** (6.119)
Central	-0.005 (0.028)	0.206 (0.570)	11.029*** (3.331)	7.351 (6.883)
Bogota	0.004 (0.026)	0.468 (0.525)	13.181*** (2.610)	18.912*** (6.014)
CR4	-0.009 (0.011)	-0.787** (0.390)	-0.406 (2.200)	-1.213 (3.233)
Spillover of PCs per employee	0.244*** (0.028)			
Spillover of ITC expenditure per employee		0.240*** (0.089)		
Spillover of LF_PC			0.473*** (0.100)	
Spillover of LF_connected				0.313 (0.213)
Constant	-0.172*** (0.050)	-9.221*** (1.696)	-56.901*** (8.795)	-67.856*** (17.558)
Observations	2,778	2,778	2,778	2,778
R-squared	0.271	0.191	0.209	0.082

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 5 (continued)  
ICT adoption affecting employees by firm size – large firms

	PCs per employee	log(ICT expenditure per worker)	Workers with PCs (%)	Workers connected to Internet (%)
log of sales	0.016*** (0.003)	0.468*** (0.167)	2.453*** (0.558)	0.590 (0.649)
% export over sales	0.016 (0.019)	0.777 (0.532)	1.107 (3.881)	18.190*** (5.504)
Dummy if foreign governance	0.014* (0.007)	0.370 (0.282)	7.001*** (1.943)	1.401 (2.157)
% college employees	0.164*** (0.023)	3.067*** (0.898)	24.990*** (6.419)	21.673*** (5.547)
% technical employees	0.091*** (0.022)	0.074 (0.945)	14.735** (5.955)	-1.240 (5.346)
Dummy innovation 2004	0.007 (0.007)	0.134 (0.228)	-0.116 (1.787)	5.243* (2.806)
Dummy Organizational change	0.011** (0.005)	0.607** (0.235)	2.195 (1.737)	3.221 (2.327)
Medium high technology	0.007 (0.007)	0.113 (0.427)	0.983 (2.032)	6.230* (3.240)
Medium low technology	-0.014** (0.006)	0.237 (0.461)	0.280 (1.896)	1.393 (1.759)
Caribe	0.009 (0.020)	2.419 (1.568)	10.778* (6.006)	-9.046 (11.252)
Pacifico	0.035* (0.021)	4.318** (1.646)	15.652** (6.164)	3.614 (11.472)
Cafetera	0.038* (0.022)	2.772 (1.816)	14.012** (5.901)	7.230 (10.382)
Central	0.031 (0.023)	3.588** (1.736)	13.553** (6.006)	1.034 (11.370)
Bogota	0.037 (0.024)	2.727 (1.796)	8.144 (5.715)	2.814 (10.320)
CR4	-0.010 (0.015)	0.945 (0.673)	-2.459 (3.725)	-14.676*** (5.014)
Spillover of PCs per employee	0.219*** (0.032)			
Spillover of ICT expenditure per employee		0.133 (0.165)		
Spillover of LF_PC			0.671*** (0.091)	
Spillover of LF_connected				-0.088 (0.131)
Constant	-0.265*** (0.062)	-4.517 (3.260)	-46.122*** (10.049)	32.604* (16.805)
Observations	981	981	981	981
R-squared	0.291	0.124	0.204	0.061

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 6  
ICT adoption affecting business performance – all firms

	d_Internet	d_webpage
log of sales	0.294*** (0.043)	0.265*** (0.020)
% export over sales	0.847** (0.366)	0.251 (0.164)
Dummy if foreign governance	0.327* (0.192)	0.155 (0.097)
% college employees	0.995*** (0.342)	0.367* (0.191)
% technical employees	0.697*** (0.241)	0.371*** (0.112)
Dummy engage innovation 2004	0.181*** (0.070)	0.269*** (0.041)
Dummy Organizational change	0.150** (0.062)	0.275*** (0.038)
Medium high technology	-0.184** (0.085)	0.173 (0.106)
Medium low technology	-0.018 (0.082)	0.090 (0.085)
Caribe	0.377 (0.450)	0.539** (0.215)
Pacifico	0.484 (0.466)	0.671*** (0.222)
Cafetera	0.332 (0.466)	0.766*** (0.218)
Central	0.177 (0.505)	0.601** (0.259)
Bogota	0.691 (0.445)	0.897*** (0.222)
CR4	-0.037 (0.202)	-0.275* (0.142)
Spillover of Internet	1.313*** (0.419)	
Spillover of Webpage		1.076*** (0.389)
Constant	-4.699*** (0.813)	-5.527*** (0.335)
Observations	3,759	3,759

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 7  
ICT adoption affecting business performance by firm size

	Small and medium-sized firms		Large Firms	
	d_Internet	d_webpage	d_Internet	d_webpage
log of sales	0.316*** (0.051)	0.216*** (0.035)	-0.125 (0.094)	0.131*** (0.042)
% export over sales	0.779** (0.387)	0.389* (0.207)	1.486* (0.888)	0.098 (0.187)
Dummy if foreign governance	0.116 (0.204)	0.192* (0.110)		0.124 (0.145)
% college employees	1.356*** (0.404)	0.441** (0.218)	-0.516 (0.391)	0.646 (0.425)
% technical employees	0.801*** (0.261)	0.445*** (0.127)	0.041 (0.581)	0.192 (0.295)
Dummy innovation 2004	0.178** (0.080)	0.294*** (0.048)	0.345 (0.217)	0.125* (0.072)
Dummy Organizational change	0.152** (0.070)	0.302*** (0.049)	0.198 (0.227)	0.192*** (0.066)
Medium high technology	-0.225** (0.089)	0.025 (0.112)	0.085 (0.233)	0.734*** (0.170)
Medium low technology	-0.059 (0.098)	-0.013 (0.090)	0.367 (0.377)	0.480*** (0.119)
Caribe	0.420 (0.500)	0.590** (0.232)	-4.141*** (1.411)	-0.016 (0.545)
Pacifico	0.557 (0.494)	0.746*** (0.267)	-3.951*** (1.262)	0.139 (0.491)
Cafetera	0.436 (0.491)	0.783*** (0.258)	-4.427*** (1.326)	0.332 (0.512)
Central	0.233 (0.535)	0.552** (0.279)	-4.013*** (1.451)	0.373 (0.548)
Bogota	0.792* (0.465)	0.949*** (0.263)	-4.266*** (1.389)	0.340 (0.515)
CR4	0.109 (0.214)	-0.247 (0.159)	-0.751 (0.586)	-0.226 (0.247)
Spillover of Internet	1.487*** (0.475)			0.194 (0.478)
Spillover of Webpage		1.431*** (0.397)	0.286 (0.990)	
Constant	-5.333*** (0.932)	-5.063*** (0.516)	8.151 (0.000)	-2.271** (0.899)
Observations	2,778	2,778	748	981

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 8  
ICT adoption affecting firm's infrastructure on technology – all firms

	d_ Internet areas	Internet applications	Networks
log of sales	0.224*** (0.017)	0.202*** (0.029)	0.165*** (0.010)
% export over sales	0.292** (0.142)	0.353** (0.152)	0.162** (0.078)
Dummy if foreign governance	0.005 (0.065)	-0.322*** (0.086)	0.091* (0.046)
% college employees	0.585*** (0.103)	0.566*** (0.208)	0.368*** (0.078)
% technical employees	0.389*** (0.070)	0.485*** (0.139)	0.161*** (0.050)
Dummy innovation 2004	0.139*** (0.040)	0.198*** (0.048)	0.066*** (0.023)
Dummy Organizational change	0.123*** (0.036)	0.118 (0.073)	0.052** (0.026)
Medium high technology	0.002 (0.044)	0.043 (0.075)	0.031 (0.029)
Medium low technology	0.011 (0.045)	0.063 (0.084)	-0.010 (0.027)
Caribe	0.501*** (0.169)	0.639** (0.304)	0.072 (0.129)
Pacifico	0.518*** (0.167)	0.458 (0.285)	0.167 (0.129)
Cafetera	0.603*** (0.175)	0.620** (0.310)	0.076 (0.126)
Central	0.425** (0.181)	0.374 (0.343)	0.109 (0.120)
Bogota	0.643*** (0.156)	0.677** (0.291)	0.152 (0.126)
CR4	-0.026 (0.089)	-0.116 (0.121)	-0.025 (0.060)
Spillover of Internet areas	0.306*** (0.069)		
Spillover of Internet applications		0.391*** (0.099)	
Spillover of Networks			0.198*** (0.068)
Constant	-2.835*** (0.273)	-2.463*** (0.479)	-1.873*** (0.132)
Observations	3,759	3,759	3,759
R-squared	0.252	0.107	0.270

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 9  
ICT adoption affecting firm's infrastructure on technology – small and medium-sized firms

	d_ Internet Areas	Internet applications	Networks
log of sales	0.299*** (0.037)	0.181*** (0.038)	0.308*** (0.039)
% export over sales	0.476* (0.252)	0.325** (0.144)	0.340* (0.206)
Dummy if foreign governance	0.179 (0.154)	-0.297*** (0.101)	0.431*** (0.097)
% college employees	0.946*** (0.159)	0.543*** (0.157)	0.911*** (0.178)
% technical employees	0.634*** (0.108)	0.413*** (0.109)	0.436*** (0.138)
Dummy innovation 2004	0.175*** (0.053)	0.136*** (0.044)	0.098* (0.058)
Dummy Organizational change	0.198*** (0.053)	0.120* (0.069)	0.196*** (0.060)
Medium high technology	-0.084 (0.057)	-0.093 (0.075)	-0.006 (0.065)
Medium low technology	-0.058 (0.061)	-0.024 (0.077)	-0.093 (0.058)
Caribe	0.637*** (0.207)	0.513 (0.314)	0.113 (0.272)
Pacifico	0.802*** (0.196)	0.465 (0.303)	0.392 (0.276)
Cafetera	0.837*** (0.210)	0.506 (0.308)	0.059 (0.251)
Central	0.531** (0.228)	0.320 (0.356)	0.028 (0.227)
Bogota	0.884*** (0.182)	0.563* (0.302)	0.309 (0.252)
CR4	-0.009 (0.126)	-0.086 (0.111)	-0.117 (0.131)
Spillover of Internet areas	0.470*** (0.108)		
Spillover of Internet applications		0.413*** (0.095)	
Spillover of Networks			0.457*** (0.154)
Observations	2,778	2,778	2,778

Robust standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 9 (continued)  
 ICT adoption affecting firm's infrastructure on technology – large firms

	d_ Internet areas	Internet applications	Networks
log of sales	0.147*** (0.039)	0.059** (0.028)	0.232*** (0.037)
% export over sales	0.399** (0.197)	0.213 (0.136)	0.348** (0.178)
Dummy if foreign governance	0.012 (0.114)	-0.186** (0.076)	-0.029 (0.094)
% college employees	0.886*** (0.309)	0.325 (0.213)	0.674*** (0.232)
% technical employees	0.259 (0.272)	0.422* (0.235)	0.114 (0.183)
Dummy innovation 2004	0.041 (0.084)	0.121 (0.093)	0.366*** (0.095)
Dummy Organizational change	0.080 (0.069)	0.044 (0.065)	-0.058 (0.082)
Medium high technology	0.330** (0.140)	0.363*** (0.109)	0.194** (0.094)
Medium low technology	0.257*** (0.097)	0.231*** (0.080)	0.133* (0.080)
Caribe	0.458 (0.482)	0.128 (0.186)	-0.236 (0.482)
Pacifico	0.101 (0.474)	-0.172 (0.193)	-0.085 (0.482)
Cafetera	0.355 (0.458)	0.107 (0.180)	-0.062 (0.481)
Central	0.317 (0.469)	-0.051 (0.176)	0.210 (0.479)
Bogota	0.388 (0.470)	0.125 (0.175)	-0.033 (0.487)
CR4	0.218 (0.264)	-0.000 (0.198)	0.095 (0.177)
Spillover of Internet areas	0.163 (0.216)		
Spillover of Internet applications		0.005 (0.130)	
Spillover of Networks			0.481** (0.218)
Observations	981	981	981

Robust standard errors in parentheses  
 \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 10  
Summary of overall findings

ICTs	Sales	Export	Foreign	Professionals	Technicians	Innovators in 2005	Organizational Changes in 2005	Epidemic Effects
PCs per employee	****	+	****	****	****	****	****	****
ICT expenditure per employee	****	+	**	****	+	****	****	****
Workers with PCs (%)	****	+	****	****	****	****	****	****
Workers connected to Internet (%)	****	**	+	****	****	+	+	****
Internet	****	**	+	****	**	**	****	****
Webpage	****	+	+	+	****	****	****	****
Internet areas	****	**	+	****	****	****	****	****
Networks	****	**	-**	****	****	****	+	****
Internet applications	****	**	+	****	****	****	**	****

Along a given ICT, each cell shows the sign of the estimated coefficient of an explanatory variable and the level of statistical significance, respectively.  
 \*\*\* p<0.01, \*\* p<0.05, \* p<0.1