Productivity effects of ICTs and organizational change: A test of the complementarity hypothesis in Spain*

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Abstract

Using firm level data, this paper explores the effect of information and communication technologies (ICTs) and organizational change on firms' productivity. In line with the most relevant empirical literature, it focuses on the complementarity between these two practices. It is argued that there are significant productivity gains associated with new organizational practices in combination with investments in ICTs. I find evidence supporting the hypothesis that the use of ICTs is complementary with organizational change, although this result depends on which ICTs variable is used. Finally, results are consistent when analyzing manufacturing and services firms separately.

Key words: ICTs; Organizational Change; Complementary

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1. Introduction

The poor productivity performance of European countries relative to the United States is an important focus for government policy (see O'Mahony and van Ark, 2003, for a review of this literature). As pointed out by Sapir et al. (2003): "In the EU, there has been a steady decline of the average growth rate decade after decade and per-capita GDP has stagnated at about 70% of the US level since the early 1980s". This debate is particularly important in the Spanish case, where productivity growth has been weak compared to other advanced economies and the OECD area. As a consequence, Spain has failed to catch up with the most advanced economies and to converge towards their productivity levels (see Mora-Sanguinetti and Fuentes, 2012).

One argument explains this productivity gap between Europe and the United States in terms of the differences in the use of information and communication technologies (ICTs) and in the adoption of organizational changes. Two recent papers confirm this hypothesis. First, Bloom et al. (2012) analyze productivity differences between seven European countries (France, Germany, Italy, Poland, Portugal, Sweden, and the United Kingdom) and the United States. They find that US multinationals obtain higher productivity from ICTs than non-US multinationals (or domestic firms) in Europe, and that this productivity gain is related to the management practices of US firms. Second, Crespi et al. (2007) show that US-owned firms operating in the United Kingdom are more likely to introduce productivity-enhancing business practices than UK-owned firms.

In this context, there are three main issues at stake: (i) the relationship between organizational change and productivity; (ii) the role of ICTs; and (iii) the possible interactions between investments in ICTs and the reorganization of the firm.

The field of organizational economics has developed rapidly over the past two decades. A good number of contributions in empirical organizational economics is focused on the relationship between organizational change and firm performance. This literature points to a clear conclusion: new organizational practices are major factors in explaining productivity differences across firms (see Ichniowski and Shaw, 2003, for a review of this literature).

The work by Black and Lynch (2004) presents one of the most significant findings regarding the relationship between organizational change and growth. The authors find that as much as 30 percent of output growth between 1993 and 1996 in US manufacturing might be accounted for by organizational practices (specifically, by workplace practices and re-engineering efforts).

Moreover, a significant body of research finds empirical evidence for a positive productivity effect of ICTs at the firm level. Dedrick et al. (2003) and Brynjolfsson and Yang (2006) present detailed surveys of main contributions to this literature. However, one of the key puzzles found by this literature is the heterogeneity of returns to the use of ICTs between firms and across countries. One possible explanation for this heterogeneity could be that whether ICTs improves a firm's productivity or not depends primarily on organizational changes that a firm makes in addition to its ICT investments. Therefore, simply focusing on the analysis of the "direct" effect of organizational change and ICTs on productivity seems not to be exhaustive. In this sense, most empirical analysis and case studies suggest that there are significant productivity gains associated with new organizational practices in combination with investments in ICTs (see Brynjolfsson and Hitt, 2000, for a review of this evidence). As a leading example of empirical analysis (besides the previously mentioned Bloom et al., 2012), Bresnahan et al. (2002) find empirical evidence supporting the interactions among adoption of information technology, skills, and organizational change. This hypothesis of complementarity is also supported by careful econometric case studies (see Baker and Hubbard, 2004, and Bartel et al., 2007).

The importance of complementary investments in ICTs and organizational change can be also analyzed from the point of view of the startup costs of ICTs implementation. In this sense, Gormley et al. (1998) show that less than 20% of the total cost of the installation of a technology designed to integrate various databases and other organizational processes is for hardware and software. The rest of the costs are spent on organization and can be mainly attributed to reorganization and training.

This paper explores the complementarity between ICTs and organizational change using a sample of Spanish firms. The existence of complementarity can be tested in different ways (see Athey and Stern, 1998, for a detailed overview of these approaches). The empirical literature has mainly focused on two approaches. The first approach, the so-called adoption approach, is based on revealed preferences and consists of computing correlations among actions. A less noisy version of this approach is based on reduced form regressions with exclusion restrictions. The idea behind it is that a factor that has an effect on one action will not be correlated with another action unless the actions are complementary. The second approach, and the one taken in this paper, is the productivity (or direct) approach. The starting point of this strategy is to start out with a performance equation (a production function in my case) and to test the existence of complementarities by regressing a measure of firm performance on combinations of specific firm practices. In particular, the empirical framework that I develop leads to the estimation of a production function depending on traditional inputs (labor, capital and materials) and combinations of variables representing the use of ICTs and the introduction of organizational changes. In this context, to test the complementarity hypothesis, I need to derive an inequality restriction as implied by the theory of supermodularity and test whether this restriction is accepted by the data.

As pointed out by Bloom et al. (2010), one of the main limitations associated with the work in organizational economics is the lack of high-quality data across large numbers of firms. Moreover, most of the existing evidence is based on cross-section data. This study attempts to overcome this limitation by taking advantage of a unique panel of Spanish firms including information on ICTs, organizational change and basic economic information of the firm. This data allows me to study interactions between ICTs and organizational change in a production function framework. Moreover, panel data allows me to account for unobserved heterogeneity, which has been a problem in previous empirical studies of complementarities (see Athey and Stern, 1998).

Data available on ICTs refers mainly to technologies to help managers access more information (like Enterprise Resource Planning software and Customer Relationship Management software). This data seems to be a more accurate measure of the ICTs effort made by firms than, for example, investment in computers, which is one of the most used proxies for ICTs investment in the existing empirical literature. In this sense, Brynjolfsson et al.

(2006) show that investment in hardware accounts for only one fifth of total costs of large scale ICTs projects (such as Enterprise Resource Planning, Customer Relationship Management, and Supply Chain Management). Besides information on technology to acquire information, I have data on human capital related to ICTs.

I also have detailed data regarding organizational change. Specifically, I have information on organizational changes related to knowledge management systems, the organization of work within the firm, and the external relations of the firm.

The rest of the paper is organized as follows. Section 2 provides the empirical framework used to estimate complentarities between ICTs and organizational change. Section 3 introduces the data and presents some descriptive analysis. Section 4 presents the results and Section 5 summarizes and concludes.

2. Modelling complementarity between ICTs and organizational change

In this section, I discuss the details of the empirical framework that is used to estimate the effects of ICTs and organizational change on firms' productivity. I examine this issue in the context of a production function. Although I analyze the "direct" effect of these variables, my main goal is to test the hypotheses that ICTs and organizational change are complements (i.e., the productivity of firms with organizational change that also invest in ICTs is higher than the productivity of other firms).

Before explaining the details of the empirical framework used, it is important to consider two characteristics of the practices under consideration which affect the way the production function is specified. First and more important, firms take time to adjust to organizational changes and new technologies. Therefore, it is reasonable to think that these practices need time to have an effect on productivity. For example, Brynjolfsson and Saunders (2010) point out that IT investments may take approximately 3 or 4 years to pay off (i.e., to have an effect on productivity). Likewise, Brynjolfsson and Hitt (2003) show that complementarities between IT and business-process reorganization can take years to come to fruition. Second, data on organizational change and ICTs presents almost no time-series variation (see Bloom et al., 2010), and therefore I cannot take advantage of the panel dimension of this data. Following the approach used by Leiponen (2005), I attempt to deal with these issues considering the variables of interest (ICTs and organizational change) to be time-invariant variables measured at the beginning of the period. Therefore, I estimate the average productivity effect of ICTs and organizational change at the beginning of the period over a 4-year period (2006-2009). This approach allows me to take into account the lag of years between the adoption of these practices and their productivity effects by using time-invariant variables.

2.1. Specification of the production function

I assume that firms face a general Cobb-Douglas production function of the form:

$$Y_{jt} = A_{jt} K_{jt}^{\alpha_k} L_{jt}^{\alpha_l} M_{jt}^{\alpha_m} \tag{1}$$

where Y_{jt} is the output of firm j in year t, A_{jt} is a firm-specific productivity factor, K_{jt} is capital, L_{jt} is labor and M_{jt} is materials. I follow Klette (1999) and express the production function in terms of logarithmic deviations from a reference point within industry (which can be thought of as a representative firm within the industry). Specifically, I characterize this reference point as the industry average value of output and inputs in each year (see, for example, Ornaghi, 2006). This approach allows me to control for unobserved industry-specific factors. As pointed out by Klette (1999), it is worth noting that this normalization eliminates the need for deflating the nominal variables.

Accordingly, the Cobb-Douglas production function (1) can be written as:

$$y_{jt} = a_{jt} + \alpha_k k_{jt} + \alpha_l l_{jt} + \alpha_m m_{jt} \tag{2}$$

where lower-case letters (y, k, l, and m) indicate that the variable is measured as the log deviation from the industry mean (for example, $y_{jt} = \ln(Y_{jt}) - \ln(\overline{Y_{it}})$ where $\overline{Y_{it}}$ is the mean output across firms in industry i in year t) and $a_{jt} = \log(A_{jt})$.[1]

I model the firm-specific productivity term as composed of discrete choice variables representing information and communication technologies (X_{j0}^{ict}) and organizational innovations

[1] Industry breakdown is defined in Table A1 in Appendix A.

(X_{j0}^{oi}) ; a time-invariant term that accounts for the heterogeneity across firms (η_j); and a firm-specific productivity shock which is assumed to be an uncorrelated zero mean error term (ε_{jt}). X_{j0}^{ict} and X_{j0}^{oi} are the main explanatory variables of interest. They are time-invariant and measured at $t = 0$.

$$a_{jt} = \beta_{ict} X_{j0}^{ict} + \beta_{oi} X_{j0}^{oi} + \eta_j + \varepsilon_{jt} \quad (3)$$

Combining equations (2) and (3), I can write:

$$y_{jt} = \alpha_k k_{jt} + \alpha_l l_{jt} + \alpha_m m_{jt} + \beta_{ict} X_{j0}^{ict} + \beta_{oi} X_{j0}^{oi} + \eta_j + \varepsilon_{jt} \quad (4)$$

2.2. Empirical method for estimating complementarities in the production function

Two practices (in my case, ICTs and organizational change) are complementary if the returns to adopting one practice are greater when the second practice is present. For continuous variables, complementarity between two variables means that the incremental effect of one variable on the objective function increases conditionally on increasing the other variable (i.e., complementarity implies that cross-partial derivatives of the objective function are positive). For discrete variables, as considered in this paper, the analysis of complementarities builds on the concept of supermodularity introduced by Topkis (1978), while Vives (1990) and Milgrom and Roberts (1990) first applied this approach to organizational economics. In this case, complementarity between discrete variables can be tested by directly testing whether the objective function (i.e., the production function) is supermodular in the discrete variables. This approach, widely used, has been applied, among others, by Cassiman and Veugelers (2006), Leiponen (2005), and Mohnen and Röller (2005).

A two-dimensional objective function $f(x, y)$, where $x = \{0, 1\}$ and $y = \{0, 1\}$, is supermodular in x and y (and therefore x and y are complements) if the following inequality restriction is satisfied:

$$f(1, 1) - f(0, 1) \geqslant f(1, 0) - f(0, 0) \quad (5)$$

Since I am interested in testing for strict complementarity, I will restrict myself to the case where (5) applies as a strict inequality. Intuitively, expression (5) implies that the effect of the adoption of an activity on performance is higher if the other activity is already being performed than if not.

To test the existence of complementarities between the time-invariant variables of interest (ICTs, X_{j0}^{ict}, and organizational change, X_{j0}^{oi}, in expression (4)), I rewrite the production function in (4) to include four mutually exclusive dummy variables denoted by z_{11j}, z_{01j}, z_{10j}, and z_{10j}, where $z_{11j} = 1$ if $X_{j0}^{ict} = X_{j0}^{oi} = 1$, and 0 otherwise; $z_{01j} = 1$ if $X_{j0}^{ict} = 0$ and $X_{j0}^{oi} = 1$, and 0 otherwise; $z_{10j} = 1$ if $X_{j0}^{ict} = 1$ and $X_{j0}^{oi} = 0$, and 0 otherwise; and $z_{00j} = 1$ if $X_{j0}^{ict} = X_{j0}^{oi} = 0$, and 0 otherwise. Now, I can write:

$$y_{jt} = \alpha_k k_{jt} + \alpha_l l_{jt} + \alpha_m m_{jt} + \gamma_{11} z_{11j} + \gamma_{01} z_{01j} + \gamma_{10} z_{10j} + \gamma_{00} z_{00j} + \eta_j + \varepsilon_{jt} \tag{6}$$

Now, the restriction that needs to be satisfied for ICTs and organizational change to be strict complementary can be written as:

$$\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00} \tag{7}$$

To test the strict inequality restriction given by expression (7), I need consistent estimates of the coefficients γ_{11}, γ_{01}, γ_{10}, and γ_{00}. The next section deals with the estimation method.

2.3. Estimation method

System GMM for panel data described in Arellano and Bover (1995) and Blundell and Bond (1998) is used for the estimation of the production function. This method allows us to account for unobserved heterogeneity and predetermined and endogenous variables. The specification of the production function here contains variables that are time-invariant (X_{j0}^{ict} and X_{j0}^{oi} in expression (4); and z_{11j}, z_{01j}, z_{10j} and z_{00j} in expression (6)). In this context, system GMM (which includes equations in first differences and equations in levels) allows us to identify these variables which are fixed for the duration of the panel. Note that standard first-difference GMM estimator cannot identify the time-invariant variables of interest. In addition, system GMM reduces the finite sample bias of the first-difference GMM estimator (see Blundell and Bond, 1998). Lagged levels of inputs (k, l and m) are used as instruments for the first differenced equations, while lagged first differences are used as instruments for the levels equations. The instruments used are detailed in the notes to the tables. Sargan tests of the overidentifying restrictions are reported for each estimate.

Athey and Stern (1998) discuss the importance of controlling for the unobserved heterogeneity to provide a consistent test for complementary. In this context, the system GMM approach used in this paper controls for unobserved firm fixed effects and for simultaneity in the choice of inputs and outputs. However, the potential endogeneity of ICTs and organizational change variables has not been discussed so far. With respect to this, as I said before, variables representing ICTs and organizational change are time-invariant and are measured at the beginning of the period. Using this specification, past and, at most, contemporaneous values of these regressors are related to productivity.[2] Therefore, it is plausible to think that this specification mitigates the potential simultaneity and endogeneity problems associated with these variables.

3. Data description

The data set used in the empirical estimation matches to two sources: (1) a panel of innovative firms (PITEC); and (2) information from the community survey on ICT usage in firms (ICT Survey). Combining these two sources, I construct a unique panel data set of firms. In order to understand the richness of the data used, it is useful to start with a description of each data source. Next, I describe the sample of firms and the key variables used in the empirical analysis.

3.1. Data sources

One rich source of detailed firm-level data is the Panel de Innovación Tecnológica (PITEC). PITEC is a firm-level panel data base for innovative activities of Spanish firms based on the Community Innovation Survey (CIS).[3] CIS data is widely used both by policy observers

[2] Specifically, I use data for the year 2006 to define the variable on ICTs and for the year 2005 to define the variable on organizational change, while productivity is defined over the period 2006-2009. Section 3 details data available and all employed variables.

[3] The Community Innovation Survey (CIS) is a survey executed by national statistical offices throughout the European Union to investigate innovation activities of firms. The CIS is carried out in Spain by the

to provide innovation indicators and trend analyses, and by economists to analyze a variety of topics related to innovation (see Mairesse and Mohnen, 2010, for a detailed review of econometric studies using CIS data). PITEC contains information for a panel of more than 11,000 firms for the period 2003-2010 as of today. Regarding its composition, PITEC consists of several subsamples, the most important of which are a sample of firms with 200 or more employees and a sample of firms with intramural R&D expenditures. Both subsamples have quite broad coverage. PITEC contains information for manufacturing and services firms.

The second data source I use is the ICT Survey.[4] This survey provides detailed information on the use of a variety of information and communication technologies. A drawback with respect to the PITEC is that the ICT Survey comes in waves of cross-sectional data, where the same firms are not necessarily sampled wave after wave. For this study, I have data for the years 2006 to 2009. Again, information for manufacturing and services firms is available.

3.2. Sample of firms

The data used is a mixture of a panel data (PITEC) for the period 2003-2010 and information from a cross-section survey (ICT Survey) for the years 2006 to 2009. From these sources, I construct a balanced panel data set for the period 2006-2009, although some pre-sample information is also used. The starting point for constructing the sample of firms is the PITEC. To be included in the sample, firms from the PITEC must have participated in the 2006, 2007, 2008 and 2009 ICT Surveys. Combining these data sources, few small-medium firms (firms with fewer than 200 employees) remain in the sample, and large firms (firms with 200 or more employees) are over-represented.[5] This is due mainly to two

Instituto Nacional de Estadística (INE) under the name *Encuesta sobre Innovación en las empresas*. The CIS follows the recommendations of the OSLO Manual on performing innovation surveys (see OECD, 2005).

[4] This survey is executed by national statistical offices. In Spain, it is carried out by the Instituto Nacional de Estadística (INE) under the name *Encuesta sobre el uso de Tecnologías de la Información y las Comunicaciones y del Comercio Electrónico en las empresas.*

[5] Only 21 small-medium firms are available for all the years from 2006 to 2009.

facts. First, large firms are more likely to survive than small ones over the period analyzed and to participate and respond to questionnaires. Here it is important to note again that the ICT Survey is a cross-sectional survey and the same firms are not necessarily sampled every year. Second, as I said before, a sample of large firms is one of the main subsamples included in the PITEC. Given this sample design which over-represents large firms, and to avoid biased results, I restrict my attention to large firms. The final sample of firms consists of 1,627 large firms belonging to manufacturing (854 firms) and service sectors (773 firms). The industry breakdown considered is defined in Table A1 in Appendix A.

3.3. Variables

This section deals with the definition and construction of the key variables. First, I describe the variables related to the use of ICTs by firms. Second, I describe the information available on organizational change. Finally, I detail the information available which is necessary to estimate a production function (firms' output, capital, labor and materials).

A. Data on ICTs

Here, the data used corresponds to the ICT Survey. The empirical specification described in Section 2 requires the variable on ICTs (X_{j0}^{ict}, in expression (4)) to be time-invariant and measure at the beginning of the period. I use data for the year 2006 to construct this variable.

The data available to characterize the use of ICTs within the firm can be divided in two groups. A first group of variables refers to the use of different applications for the automatic share of information within the firm. First, I have information on whether or not the firm is using an Enterprise Resource Planning software package to share information on sales and/or purchases with other internal functional areas (ERP). ERP consists of one or of a set of software applications that integrate information and processes across the several business functions of the firm. Typically, ERP integrates planning, procurement, sales, marketing, customer relationship, finance and human resources.

Second, information on the use of any software application for managing information about clients (Customer Relationship Management) is available (CRM). CRM is a management methodology which places the customer at the center of the business activity, based on an intensive use of information technologies to collect, integrate, process and analyze information related to the customers.

A second group of variables refers to human capital-related variables. Specifically, I have information on whether or not firms provide training to develop or upgrade ICTs-related skills to their employees (Training). A second variable refers to the availability of ICTs specialists within the firm (Specialists).

B Data on organizational change

Our measures of organizational change come from the PITEC. Again, the empirical specification requires the variable on organizational change (X_{j0}^{oi}, in expression (4)) to be time-invariant and measure at the beginning of the period. Data on organizational change is not available in the year 2006 and, therefore, in this case I use the information for the year 2005 to define this variable. The data available allows me to distinguish between three different types of organizational changes. In particular, firms are asked to report whether or not they have introduced the following organizational innovations during the last three years (period 2003-2005):

i) New or significantly improved knowledge management systems to better use or exchange information, knowledge and skills within the firm (OI_Management).

ii) A major change to the organization of work within the firm, such as changes in the management structure or integrating different departments or activities (OI_Work).

iii) New or significant changes in the firm's relations with other firms or public institutions, such as through alliances, partnerships, outsourcing or sub-contracting (OI_Relations).

Given this information, I also construct a variable indicating whether or not the firm has introduced at least one of the above organizational innovations (OI_Any).

C. Data on output and inputs in the production function

The PITEC provides information on firms' economic data necessary in the estimation of a production function. In particular, it provides information on sales, number of employees and investment in physical capital. Physical capital is constructed for each firm by cumulating the physical investments using the perpetual inventory method, starting from a presample capital estimate and using a depreciation rate equal to 0.1. I use the following perpetual inventory formula $K_t = (1 - \delta)K_{t-1} + I_t$, where I_t is the investment in physical capital in year t, K_t is the capital stock in year t, and δ (=0.1) is the assumed depreciation rate. Initial capital stock is calculated following Hall et al. (1988) as follows $K_{t_0} = \frac{I_{t_1}}{\delta+g}$, where K_{t_0} is the initial capital stock, I_{t_1} is the investment in the first year available, and g is the presample growth rate of capital per year. In practice, I have characterized I_{t_1} as the firm's mean of the investment in physical capital for the observed period, and I use data of physical investments starting in 2003. Industry-specific presample growth rates of capital are defined using data of the mean gross fixed capital formation for the period 2000-2004 provided by the INE (the Spanish National Institute of Statistics).[6] To sum up, the PITEC provides information to define sales (y), employment (l) and capital (k) for the years 2006 to 2009.

Materials is an important input in the production function. Although the PITEC does not have data on materials, the ICT Survey does. Specifically, this survey provides data on total purchases of goods and services in value terms and excluding VAT. I have data on this variable for the years 2006 to 2009.

So far I have described the data used in the estimation of the production function introduced in Section 2. Table 1 summarizes variable names used, definitions, data source and years used, while Table 2 reports descriptive statistics of these variables for the whole sam-

[6] The industry breakdown provided by the INE is: Food products, beverages and tobacco products; Textiles and clothing; Leather and footwear; Wood and products of wood and cork; Paper, publishing, printing and reproduction; Coke, refined petroleum products; Chemicals and chemical products; Rubber and plastic products; Other non-metallic mineral products; Metal products; Machinery and equipment; Electrical machinery, apparatus and electronic components; Transport equipment; Other manufacturing products; Wholesale, retail trade and repair of motor vehicles and motorcycles; Hotels and restaurants; Transport and communications; Financial intermediation; Real estate activities and professional, scientific and technical activities; Other services activities.

ple of firms as well as for manufacturing and services separately. The descriptive statistics indicate that, on average, manufacturing firms are more likely to use ICTs (especially ERP software packages) and to introduce organizational innovations than service firms.

Table 3 shows the frequency with which firms combine the use of ICTs and the adoption of organizational innovations. Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, and z_{00}) refers to the variables on top of each column. For example, in column (1), z_{11} identifies firms using ERP and with any organizational innovation, z_{01} identifies firms not using ERP and with any organizational innovation, z_{10} identifies firms using ERP and without organizational innovation, and z_{00} identifies firms not using ERP and without organizational innovation. Table 3 reports these frequencies for the whole sample of firms as well as for manufacturing and services separately. In some cases, and especially for manufacturing firms, I have very few observations of the mixed cases. For example, I find that only 54 manufacturing firms (6.32%) report using ERP and not having adopted any organizational innovation. This fact may have implications for the regression results. For example, Leiponen (2005) finds that, in this situation with few observations for mixed cases, estimated coefficients tend to become less reliable and less significant.

Besides asking about the introduction of organizational innovations, the PITEC contains other interesting information related to this type of innovation. Specifically, I have information about the objectives that firms pursue when introducing organizational changes. In what follows, I briefly describe this data.

Objectives of organizational innovation

Firms are asked to rate the importance of five objectives for the firm's organizational innovations in the years 2008 and 2009: (i) reduce time to respond to customer or supplier needs; (ii) improve ability to develop new products or processes; (iii) improve quality of goods or services; (iv) reduce costs per unit output; and (v) improve communication or information-sharing within the firm or with other firms or institutions. These variables are collected only for the subset of the firms which report having introduced organizational innovation.

Although these variables are of a subjective nature (largely based on the appreciation of the respondents), they provide valuable information that allows us to relate organizational change directly to strategic objectives (response time; technological innovation; quality; costs; and information and communication) affecting firms' performance.

For each of the objectives described above, firms are asked to rate their importance on a Likert scale of 1 to 4, where 1 represents high importance, 2 represents intermediate importance, 3 represents low importance and 4 represents irrelevance. In doing the descriptive analysis, I use the answers arranged on this four-point scale and I present the average values of the answers for the years 2008 and 2009. Figure 1 summarizes the importance of the objectives of organizational innovation for all firms as well as for manufacturing and services separately. Considering the whole sample of firms, the descriptive statistics suggest that firms rate the considered objectives similarly, with a slightly higher importance given to reduce time to respond and to improve quality. Regarding ICTs, around 80% of firms report that improving communication or information-sharing has high or medium importance as an objective of organizational innovation. Results by sector show that, for service firms, communication or information sharing is the main objective of organizational innovation.

In summary, more than only a classification of objectives, this descriptive analysis supports the idea that firms are aware of the relationship between ICTs and organizational change. This conclusion is based on the opinion of the firms (and more specifically, on the appreciation of the respondents of the questionnaire). The next section is aimed at presenting econometric evidence on the possible interactions between ICTs and organizational change.

4. Empirical results

This section presents the empirical results. First, I present as a base case the results from estimating the effects of ICTs and organizational change without taking into account the existence of complementarities. In doing this, I present the results for the estimation of production functions given by expression (4). Next, I come back to the main goal of this paper and I focus on exploring the interactions between ICTs and organizational change. In this case, the production function to be estimated is given by expression (6). All estimates include year dummies and a dummy for manufacturing firms. Moreover, each estimate includes m_1 and m_2 Arellano and Bond (1991) test statistics for first and second-order serial correlation.

4.1. Results for the base case

Table 4 presents the results for the estimation of expression (4) including only the time-invariant indicator that describes ICTs (variable X_{j0}^{ict} in expression (4)). Four different variables related to the use of ICTs (defined in Section 3.3) are analyzed, ERP, CRM, $Training$ and *Specialists*. First, column (1) in Table 4 presents the estimation results for the specification with traditional inputs only (k, l and m). Estimated elasticities for these inputs show plausible values. Columns (2) to (5) in Table 4 present the results for each of the four variables on ICTs. The use of CRM systems has a positive and significant coefficient. The coefficients of the other three indicators are not statistically different from zero. Column (6) in Table 4 presents the results for the specification with these four indicators together. Consistent with the previous results, CRM has a positive and significant coefficient. Moreover, the *Specialists* variable is estimated more precisely and it turns out to be significant.

Now I focus on the effect of organizational change. In doing this, I estimate expression (4) , including only the time-invariant indicator that describes organizational change (variable X_{j0}^{oi} in expression (4)). Table 5 shows the results for having any organizational innovation (column (1)), and for having each of the three types of organizational innovations defined in Section 3.3 (columns (2) to (5)). The coefficients of organizational innovation variables are not statistically different from zero. At this point, I do not find evidence supporting the existence of an effect of organizational changes on future productivity. Note that the approach used here may underestimate the effects of the time-invariant variables if the lag between their adoption and their effects is too large. This may be of special importance for variables related to organizational innovation since these variables refer to the period

2003-2005.

Table 6 shows the results for the estimation of expression (4), including both ICTs and organizational change variables. First, I present results for the whole sample of firms (columns (1) to (5)). Consistent with the previous findings, CRM and *Specialists* have positive and significant coefficients. The rest of the coefficients are not statistically different from zero. I also present results for manufacturing firms (column (6)) and for services (column (7)) separately. Results by sector show that there are no important differences between manufacturing firms and services, although input coefficients, and especially capital coefficient, are estimated with less precision.

Finally, it is important to note that the estimated coefficients of traditional inputs (k, l and m) across Tables 4, 5 and 6 are robust to the inclusion of ICTs and organizational change variables, and the results of the specification tests do not indicate any problem.

4.2. Testing for complementarities

Table 7 presents the main results for the complementarity between ICTs and organizational change. Now, expression (6) is the equation to be estimated. Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, and z_{00}) refer to the variables on top of each column. To test complementarity, I perform a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$ (see Cassiman and Veugelers, 2006, for a similar application). Before discussing complementarities, it is important again to note that the estimated coefficients of traditional inputs show plausible values, and the results of the specification tests do not indicate any problem.

Columns (1) to (4) in Table 7 present the results for the interactions among each of the ICTs variables considered (ERP, CRM, $Training$ and *Specialists*) and the dummy variable indicating having introduced any organizational innovation (OI_Any). I find evidence supporting the existence of complementarity between the use of CRM and organizational change (p-value=0.005). However, complementarity is seen to be rejected when analyzing the rest of the ICTs indicators. In some cases, this low significance may be partially due to the fact that there are few observations for the mixed cases z_{01} and z_{10} (see Table 3).

To examine in more detail the interaction between the use of CRM and organizational change, columns (5) to (7) in Table 7 show the results when splitting the variable of "any organizational innovation" into its three components ($OI\_Management$, OI_Work, and $OI\_Relations$). I control for the excluded organizational innovations in each estimate (for example, in column (5) , I include a dummy for changes in the organization of work, OI_Work, and a dummy for changes in the relations, $OI\_Relations$).[7] Complementarity between the use of CRM and changes related to new or significantly improved knowledge management systems is accepted at 10% (p-value=0.075). Evidence is strong for complementarity with changes on the organization of work (p-value=0.001) and changes in the relations with other agents (p-value=0.000). As a robustness check, Table A2 in Appendix A replicates the specifications in Table 7, controlling for the excluded ICTs variables in each specification. For example, column (1) in Table A2 include the dummy variables CRM, $Training$ and $Specialists$. The results shown in Table A2 are similar to those in Table 7.

Finally, I look at the manufacturing and service sectors separately to see if the interaction between ICTs and organizational change differs across the two sectors. To simplify the presentation, Table 8 shows the estimated coefficients of the mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, and z_{00}) and the results of the complementarity tests. The specifications here are the same as in Table 7. Estimated coefficients of traditional inputs (not reported in Table 8) are similar to those in columns (6) and (7) of Table 6, and the results of the specification tests (also not reported) do not indicate any problem. Consistent with the previous results, evidence on complementarity between ICTs and organizational change is restricted to the use of CRM. For manufacturing firms, I find evidence for complementarity (at different significance levels) between the use of CRM and two types of organizational innovation: changes on the organization of work (p-value=0.023); and changes in the relations with other agents (p-value=0.059). Evidence for complementarity is strong for services. In this case, the results confirm complementarity between the use of CRM and the dummy variable indicating having introduced any organizational innovation (p-value=0.009), and between the use of CRM and each of the three organizational innovations considered sepa-

[7] Results are very similar if these variables are not included in the specification.

rately (p-values equal to 0.058, 0.018, and 0.020, respectively).

5. Summary and conclusions

This paper is aimed at exploring the effect of ICTs and organizational change on firms' productivity. Recent empirical literature has stressed the relevance of the interactions between these practices. For example, the effect of ICTs on firms' productivity depends on changes of the organizational design that a firm makes in addition to its ICTs investments. In line with this literature, I focus on the complementarity between ICTs and organizational change. In doing this, I use a rich panel data set of Spanish firms with detailed information on the use of technology to share information within the firm, measures of human capital related to ICTs, and organizational changes introduced by firms. Moreover, panel data allows me to account for unobserved heterogeneity, which has been a problem in previous empirical studies of complementarities.

To study the complementarity hypothesis, I use the productivity (or direct) approach. My starting point is the estimation of a production function depending on traditional inputs (labor, capital and materials) and combinations of variables representing the use of ICTs and the introduction of organizational changes. Next, I test an inequality restriction as implied by the theory of supermodularity to determine whether the complementarity hypothesis is accepted by the data.

To summarize the results, first, when analyzing the "direct" effect of ICTs and organizational change on productivity, I find evidence supporting the existence of a "direct" effect of two of the ICTs variables analyzed: the use of CRM (a software application for managing information about clients), and the availability of ICT specialists within the firm. But I do not find evidence in support of a "direct" effect for organizational change. Second, the empirical evidence here suggests that there is complementarity between ICTs and organizational change. However, this result depends on which ICTs variable is used. Specifically, the use of CRM seems to interact with organizational changes to enhance productivity. This interaction effect is significant across the three types of organizational innovation analyzed (new or significantly improved knowledge management systems; change to the organization of work within the firm; and changes in the firm's relations with other firms or public institutions). Finally, I find that there are no important differences between manufacturing firms and services, although evidence for complementarity between the use of CRM and organizational change is strong for services.

This study sheds light on the role of ICTs and organizational change as productivity shifters. Most importantly, and consistent with the existing literature, the results here point out the role of the interaction between ICTs and organizational change. Related to this, I find that changes in the organizational design of the firm have an effect on productivity only when they are accompanied by ICTs investments.

A caveat of this study is that, due to data availability, it restricts attention to a sample of large firms. This is of special importance in Spain, where the population of firms is characterized by a large share of small-medium enterprises (SMEs). Spanish SMEs represent a high share of the economy, accounting for a far larger share of total employment and value added than the EU average. Regarding the variables of interest here, it has been found that large firms are more likely to adopt organizational innovations (see Lynch, 2007, for evidence for the US, and Fariñas and López, 2011, for evidence for Spain) and ICTs (see, for example, Astebro, 2002, and Battisti and Stoneman, 2005). Further research is needed to confirm the results in this paper for SMEs.

Appendix A. Additional tables

[Insert Table A1]

[Insert Table A2]

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Table 1. Variable definitions

Variable	Definition	Source	Year(s)
Organizational Change[1]			
OI_Management	Dummy which takes the value 1 if the firm reports having introduced new or significantly improved knowledge management systems	PITEC	2005
OI_Work	Dummy which takes the value 1 if the firm reports having introduced a major change to the organization of work within the firm	PITEC	2005
OI_Relations	Dummy which takes the value 1 if the firm reports having introduced new or significant changes in the relations with other firms or public institutions	PITEC	2005
OI_Any	Dummy which takes the value 1 if the firm reports having introduced any of the above organizational innovations	PITEC	2005
Information and Communication Technologies			
ERP	Dummy which takes the value 1 if the firm has in use an Enterprise Resource Planning software package	ICT Survey	2006
CRM	Dummy which takes the value 1 if the firm has in use any software application for managing information about clients	ICT Survey	2006
Training	Dummy which takes the value 1 if the firm provides training to develop or upgrade ICT related skills to their employees	ICT Survey	2006
Specialists	Dummy which takes the value 1 if the firm has ICT specialists	ICT Survey	2006
Output and inputs[2]			
y	Log of sales of of goods and services	PITEC	2006-2009
k	Log of physical capital. Physical capital is constructed by cumulating the physical investments using the perpetual inventory method[3]	PITEC	2006-2009
l	Log of number of employees	PITEC	2006-2009
m	Log of purchases of goods and services	ICT Survey	2006-2009

[1]These variables refer to a three-year period (2003-2005) and correspond to the answers from the questionnaire of the year 2005.
[2]In the empirical analysis these variables are defined as log deviation from the industry mean (see Klette, 1999).
[3]In constructing the physical capital I use data of physical investments starting in 2003.

Table 2. Variable descriptive statistics

	Mean	St. dev	Min	Max
	All firms			
y	18.188	1.381	11.427	23.232
k	16.526	2.197	6.685	23.219
l	6.302	0.922	0.693	10.633
m	17.359	1.958	7.813	23.187
ERM	0.657		0	1
CRM	0.442		0	1
Training	0.666		0	1
Specialists	0.471		0	1
OI_Any	0.460		0	1
OI_Management	0.368		0	1
OI_Work	0.329		0	1
OI_Relations	0.136		0	1
	Manufacturing			
y	18.445	1.132	14.236	23.232
k	17.144	1.521	10.214	22.495
l	6.090	0.709	3.951	9.374
m	17.919	1.354	10.060	23.187
ERM	0.812		0	1
CRM	0.450		0	1
Training	0.765		0	1
Specialists	0.549		0	1
OI_Any	0.510		0	1
OI_Management	0.409		0	1
OI_Work	0.375		0	1
OI_Relations	0.156		0	1
	Services			
y	17.904	1.565	11.427	22.947
k	15.842	2.591	6.685	23.219
l	6.536	1.064	0.693	10.633
m	16.739	2.305	7.813	22.749
ERM	0.485		0	1
CRM	0.433		0	1
Training	0.556		0	1
Specialists	0.384		0	1
OI_Any	0.404		0	1
OI_Management	0.322		0	1
OI_Work	0.276		0	1
OI_Relations	0.112		0	1

Table 3. Frequency of mutually exclusive dummy variables representing ICTs and Organizational Change

	(1) ERP, OI_Any	(2) CRM, OI_Any	(3) Training, OI_Any	(4) Specialists, OI_Any
	All firms			
z_{11}	567 (34.85%)	365 (22.43%)	570 (35.03%)	435 (26.74%)
z_{01}	502 (30.85%)	355 (21.82%)	514 (31.59%)	331 (20.34%)
z_{10}	182 (11.19%)	384 (23.60%)	179 (11.00%)	314 (19.30%)
z_{00}	376 (23.11%)	523 (32.15%)	364 (22.37%)	547 (33.62%)
	Manufacturing			
z_{11}	382 (44.73%)	211 (24.71%)	358 (41.92%)	265 (31.03%)
z_{01}	312 (36.53%)	174 (20.37%)	296 (34.66%)	204 (23.89%)
z_{10}	54 (6.32%)	225 (26.35%)	78 (9.13%)	171 (20.02%)
z_{00}	106 (12.41%)	244 (28.57%)	122 (14.29%)	214 (25.06%)
	Services			
z_{11}	185 (23.93%)	154 (19.92%)	212 (27.43%)	170 (21.99%)
z_{01}	190 (24.58%)	181 (23.42%)	218 (28.20%)	127 (16.43%)
z_{10}	128 (16.56%)	159 (20.57%)	101 (13.07%)	143 (18.50%)
z_{00}	270 (34.93%)	279 (36.09%)	242 (31.31%)	333 (43.08%)

Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, z_{00}) refers to the variables on top of each column.

Table 4. Productivity effects of ICTs

Sample period: 2006-2009
N^o of firms: 1,627
Dependent variable: y

Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
k	0.115*	0.112*	0.111*	0.114*	0.118*	0.117*
	(0.066)	(0.067)	(0.065)	(0.067)	(0.067)	(0.067)
l	0.429***	0.441***	0.430***	0.424***	0.415***	0.420***
	(0.118)	(0.122)	(0.117)	(0.115)	(0.113)	(0.114)
m	0.318**	0.298**	0.303**	0.323**	0.330**	0.313**
	(0.143)	(0.144)	(0.143)	(0.141)	(0.141)	(0.142)
ERP		0.008				−0.085
		(0.086)				(0.052)
CRM			0.148*			0.146**
			(0.077)			(0.057)
Training				0.058		0.011
				(0.082)		(0.050)
Specialists					0.099	0.102**
					(0.075)	(0.052)
m_1	−4.090	−4.108	−4.114	−4.128	−4.115	−4.106
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
m_2	−0.557	−0.615	−0.592	−0.542	−0.518	−0.559
(p-value)	(0.578)	(0.538)	(0.554)	(0.588)	(0.604)	(0.576)
Sargan test (df=11)	14.696	14.852	14.207	14.732	14.890	14.969
(p-value)	(0.197)	(0.189)	(0.222)	(0.195)	(0.188)	(0.184)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
***significant at 1%, **significant at 5%, *significant at 10%.

Table 5. Productivity effects of Organizational Change

Sample period: 2006-2009					
N^o of firms: 1,627					
Dependent variable: y					
Independent variables	(1)	(2)	(3)	(4)	(5)
k	0.118*	0.117*	0.117*	0.113*	0.117*
	(0.066)	(0.066)	(0.066)	(0.066)	(0.065)
l	0.427***	0.427***	0.428***	0.430***	0.427***
	(0.118)	(0.118)	(0.119)	(0.119)	(0.118)
m	0.324**	0.321**	0.318**	0.312**	0.316**
	(0.145)	(0.145)	(0.144)	(0.144)	(0.145)
OI	−0.001				
	(0.039)				
OI_Management		0.013			0.005
		(0.042)			(0.041)
OI_Work			0.017		0.010
			(0.036)		(0.035)
OI_Relations				0.029	0.017
				(0.055)	(0.049)
m_1	−4.057	−4.056	−4.083	−4.090	−4.066
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
m_2	−0.543	−0.550	−0.557	−0.571	−0.561
(p-value)	(0.587)	(0.582)	(0.577)	(0.567)	(0.575)
Sargan test (df=11)	14.644	14.697	14.708	14.646	14.665
(p-value)	(0.199)	(0.197)	(0.196)	(0.199)	(0.198)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
***significant at 1%, **significant at 5%, *significant at 10%.

Table 6. Productivity effects of ICTs and Organizational Change

Sample period: 2006-2009
N^o of firms: 1,627
Dependent variable: y

Independent variables	(1)	(2)	(3)	(4)	(5)	(6) Manufacturing 854 firms	(7) Services 773 firms
k	0.115*	0.114*	0.116*	0.118*	0.117*	0.072	0.097
	(0.067)	(0.065)	(0.066)	(0.066)	(0.065)	(0.093)	(0.080)
l	0.440***	0.430***	0.425***	0.417***	0.423***	0.408**	0.542***
	(0.121)	(0.117)	(0.116)	(0.114)	(0.114)	(0.192)	(0.153)
m	0.303**	0.307**	0.325**	0.331**	0.313**	0.422**	0.208
	(0.146)	(0.144)	(0.142)	(0.142)	(0.142)	(0.192)	(0.169)
ERP	0.001				−0.084	−0.075	−0.025
	(0.082)				(0.052)	(0.050)	(0.106)
CRM		0.144*			0.146**	0.117**	0.191**
		(0.075)			(0.057)	(0.059)	(0.092)
Training			0.056		0.012	0.014	0.059
			(0.078)		(0.049)	(0.039)	(0.088)
Specialists				0.100	0.102**	0.107**	0.094
				(0.072)	(0.051)	(0.049)	(0.093)
OI	0.004	−0.004	−0.008	−0.019	−0.0145	−0.025	0.014
	(0.034)	(0.037)	(0.033)	(0.031)	(0.029)	(0.039)	(0.052)
m_1	−4.076	−4.082	−4.112	−4.109	−4.107	−2.966	−3.562
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)
m_2	−0.605	−0.582	−0.537	−0.516	−0.562	0.023	−1.140
(p-value)	(0.545)	(0.560)	(0.591)	(0.606)	(0.574)	(0.981)	(0.254)
Sargan test (df=11)	14.860	14.143	14.660	14.765	14.882	12.098	9.753
(p-value)	(0.189)	(0.225)	(0.199)	(0.193)	(0.188)	(0.356)	(0.552)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms (except estimates 6 and 7), but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
***significant at 1%, **significant at 5%, *significant at 10%.

Table 7. Complementarity between ICTs and Oganizational Change

Sample period: 2006-2009
N^o of firms: 1,627
Dependent variable: y

Independent variables	(1) ERP, OI_Any	(2) CRM, OI_Any	(3) Training, OI_Any	(4) Specialists, OI_Any	(5) CRM, OI_Management	(6) CRM, OI_Work	(7) CRM, OI_Relations
k	0.113*	0.119*	0.115*	0.117*	0.116*	0.116*	0.122*
	(0.066)	(0.065)	(0.065)	(0.065)	(0.065)	(0.066)	(0.064)
l	0.439***	0.422***	0.423***	0.417***	0.426***	0.425***	0.425***
	(0.121)	(0.118)	(0.115)	(0.113)	(0.117)	(0.119)	(0.118)
m	0.301**	0.304**	0.326**	0.334**	0.299**	0.299**	0.292**
	(0.145)	(0.144)	(0.143)	(0.140)	(0.143)	(0.144)	(0.142)
z_{11}	0.135	0.252**	0.173	0.229**	0.229**	0.274**	0.317***
	(0.114)	(0.108)	(0.117)	(0.103)	(0.112)	(0.139)	(0.107)
z_{01}	0.131	0.186	0.201	0.235**	0.191	0.171	0.186
	(0.126)	(0.130)	(0.125)	(0.119)	(0.131)	(0.132)	(0.132)
z_{10}	0.135	0.041	0.157	0.115	0.038	0.011	−0.050
	(0.188)	(0.178)	(0.176)	(0.169)	(0.180)	(0.210)	(0.191)
z_{00}	0.123	0.102	0.118	0.149	0.070	0.082	0.073
	(0.206)	(0.195)	(0.205)	(0.175)	(0.198)	(0.197)	(0.195)
OI_Management						−0.0004	−0.003
						(0.039)	(0.039)
OI_Work					0.009		0.014
					(0.035)		(0.035)
OI_Relations					0.010	0.011	
					(0.047)	(0.047)	
Complementarity test, p-value	0.559	0.005	0.883	0.289	0.075	0.001	0.000
m_1	−4.083	−4.070	−4.085	−4.122	−4.105	−4.079	−4.125
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
m_2	−0.606	−0.581	−0.532	−0.509	−0.597	−0.597	−0.613
(p-value)	(0.544)	(0.561)	(0.594)	(0.610)	(0.550)	(0.550)	(0.539)
Sargan test (df=11)	14.863	14.172	14.728	14.777	14.152	14.229	14.032
(p-value)	(0.189)	(0.223)	(0.195)	(0.192)	(0.224)	(0.220)	(0.231)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, z_{00}) refers to the variables on top of each column.
Complementarity test is a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$. The p-values for these tests are reported.
***significant at 1%, **significant at 5%, *significant at 10%.

Table 8. Complementarity between ICTs and Organizational Change
Manufacturing and services results

	(1) ERP, OI_Any	(2) CRM, OI_Any	(3) Training, OI_Any	(4) Specialists, OI_Any	(5) CRM, OI_Management	(6) CRM, OI_Work	(7) CRM, OI_Relations
Manufacturing (854 firms)							
z_{11}	0.146	0.225*	0.166	0.186	0.216*	0.290**	0.293**
	(0.124)	(0.124)	(0.134)	(0.120)	(0.130)	(0.117)	(0.120)
z_{01}	0.161	0.232*	0.199*	0.225**	0.244**	0.213*	0.232*
	(0.123)	(0.119)	(0.119)	(0.111)	(0.114)	(0.122)	(0.119)
z_{10}	0.161	0.096	0.127	0.084	0.102	0.093	0.048
	(0.185)	(0.153)	(0.151)	(0.144)	(0.158)	(0.165)	(0.163)
z_{00}	0.172	0.133	0.130	0.102	0.127	0.147	0.146
	(0.144)	(0.146)	(0.169)	(0.140)	(0.148)	(0.143)	(0.148)
Complementarity test, p-value	0.517	0.290	0.667	0.651	0.527	0.023	0.059
Services (773 firms)							
z_{11}	0.057	0.234**	0.110	0.177	0.226*	0.195	0.299**
	(0.130)	(0.116)	(0.141)	(0.116)	(0.121)	(0.210)	(0.142)
z_{01}	0.001	0.088	0.101	0.095	0.101	0.095	0.104
	(0.145)	(0.159)	(0.174)	(0.150)	(0.173)	(0.169)	(0.168)
z_{10}	−0.073	−0.077	0.039	−0.001	−0.050	−0.132	−0.113
	(0.255)	(0.244)	(0.289)	(0.253)	(0.254)	(0.340)	(0.265)
z_{00}	−0.113	−0.004	−0.015	0.038	−0.023	−0.017	−0.045
	(0.297)	(0.279)	(0.324)	(0.258)	(0.302)	(0.304)	(0.298)
Complementarity test, p-value	0.431	0.009	0.683	0.116	0.058	0.018	0.020

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.
Estimated coefficients of traditional inputs (k, l, and m) are not reported.
Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.
Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.
Instruments for the levels equations: k, l and m lagged differences t-1.
Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, z_{00}) refers to the variables on top of each column.
Complementarity test is a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$. The p-values for these tests are reported.
**significant at 5%, *significant at 10%.

Table A1. Industry definitions

Manufacturing		Services	
Industry	NACE Code	Industry	NACE Code
Food products and beverages	15	Sale, maintenance and repair of motor vehicles	50
Tobacco products	16	Wholesale trade	51
Textiles	17	Retail trade	52
Wearing apparel; dressing and dyeing of fur	18	Hotels and restaurants	55
Leather and footwear	19	Transport	62
Wood and of products of wood and cork	20	Auxiliary transport activities; travel agencies	63
Pulp, paper and paper products	21	Post and courier activities	641
Publishing, printing and reproduction	22	Telecommunications	642
Coke, refined petroleum products	23	Real estate activities	70
Chemicals and chemical products	24 (except 244)	Renting of machinery and equipment	71
		Software consultancy and supply	722
Pharmaceuticals	244	Computer and related activities	72 (except 722)
Rubber and plastic products	25		
Ceramic tiles and flags	263	Research and development	73
Other non-metallic mineral products	26 (except 263)	Architectural and engineering activities	742
		Technical testing and analysis	743
Basic ferrous metals	27 (except 274)	Other business activities	74 (except 742, 743)
Basic precious and non-ferrous metals	274	Motion picture and video activities	921
Fabricated metal products	28	Radio and television activities	922
Machinery and equipment	29		
Electrical machinery and apparatus	31		
Electronic components	321		
Radio, television and communication equipment	32 (except 321)		
Medical, precision and optical instruments	33		
Motor vehicles	34		
Building and repairing of ships and boats	351		
Other transport equipment	35 (except 351)		
Furniture	361		
Games and toys	365		
Manufacturing n.e.c.	36 (except 361, 365)		
Recycling	37		

Table A2. Complementarity between ICTs and Oganizational Change. Robustness check

Sample period: 2006-2009

N^o of firms: 1,627

Dependent variable: y

Independent variables	(1) ERP, OI_Any	(2) CRM, OI_Any	(3) Training, OI_Any	(4) Specialists, OI_Any	(5) CRM, OI_Management	(6) CRM, OI_Work	(7) CRM, OI_Relations
k	0.115*	0.121*	0.116*	0.116*	0.120*	0.120*	0.127*
	(0.066)	(0.066)	(0.065)	(0.065)	(0.065)	(0.066)	(0.065)
l	0.418***	0.416***	0.421***	0.422***	0.417***	0.416***	0.415***
	(0.113)	(0.115)	(0.114)	(0.114)	(0.114)	(0.115)	(0.115)
m	0.315**	0.310**	0.314**	0.316**	0.309**	0.308**	0.302**
	(0.141)	(0.142)	(0.143)	(0.141)	(0.141)	(0.142)	(0.141)
z_{11}	-0.011	0.246	0.073	0.180	0.235	0.282	0.325*
	(0.192)	(0.182)	(0.196)	(0.195)	(0.179)	(0.203)	(0.169)
z_{01}	-0.001	0.198	0.110	0.183	0.210	0.186	0.203
	(0.198)	(0.194)	(0.197)	(0.209)	(0.196)	(0.197)	(0.195)
z_{10}	0.068	0.041	0.106	0.067	0.051	0.024	-0.043
	(0.233)	(0.236)	(0.226)	(0.238)	(0.234)	(0.260)	(0.243)
z_{00}	0.086	0.107	0.068	0.093	0.086	0.096	0.090
	(0.236)	(0.235)	(0.242)	(0.232)	(0.238)	(0.238)	(0.237)
ERP		-0.079	-0.086*	-0.084	-0.083	-0.079	-0.085
		(0.052)	(0.051)	(0.052)	(0.052)	(0.052)	(0.052)
CRM	0.145**		0.146**	0.144**			
	(0.057)		(0.058)	(0.057)			
Training	0.012	0.013		0.012	0.013	0.013	0.015
	(0.049)	(0.050)		(0.050)	(0.050)	(0.050)	(0.050)
Specialists	0.103**	0.100**	0.103**		0.101**	0.103**	0.102**
	(0.050)	(0.050)	(0.050)		(0.050)	(0.050)	(0.050)
OI_Management						-0.008	-0.011
						(0.035)	(0.034)
OI_Work					0.006		0.011
					(0.036)		(0.036)
OI_Relations					0.001	0.002	
					(0.043)	(0.043)	
Complementarity test, p-value	0.451	0.011	0.909	0.335	0.117	0.001	0.000
m_1	-4.109	-4.095	-4.081	-4.123	-4.109	-4.088	-4.123
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
m_2	-0.551	-0.561	-0.556	-0.554	-0.565	-0.565	-0.579
(p-value)	(0.581)	(0.575)	(0.577)	(0.579)	(0.572)	(0.571)	(0.562)
Sargan test (df=11)	14.960	14.887	14.980	14.901	14.922	14.965	14.805
(p-value)	(0.184)	(0.187)	(0.183)	(0.187)	(0.186)	(0.184)	(0.191)

Standard errors robust to heteroskedasticity of estimated coefficients are given in parentheses.

Estimates include year dummies and a dummy for manufacturing firms, but they are not reported.

Instruments for the differenced equations: k lagged levels t-2; l and m lagged levels t-2 and t-3.

Instruments for the levels equations: k, l and m lagged differences t-1.

Mutually exclusive dummy variables (z_{11}, z_{01}, z_{10}, z_{00}) refers to the variables on top of each column.

Complementarity test is a one-sided test of H_0: $\gamma_{11} - \gamma_{01} \leq \gamma_{10} - \gamma_{00}$ against H_a: $\gamma_{11} - \gamma_{01} > \gamma_{10} - \gamma_{00}$. The p-values for these tests are reported.

***significant at 1%, **significant at 5%, *significant at 10%.

Figure 1. Objectives of organizational innovation