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Original article

Innovation and productivity in services and manufacturing: the role of ICT

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Abstract

Several studies have highlighted information and communications technologies (ICTs) as a driver for firms' innovation and productivity in developed countries. However, the evidence about the impacts of ICTs vis-a-vis other innovation activities on technological and nontechnological innovation and productivity for developing countries is extremely scarce. This scarcity of research is particularly acute for the services sector, especially when it comes to assessing how it fares in comparison with the manufacturing sector. Our research contributes to closing this knowledge gap by estimating a Crépon, Duguet and Mairesse (CDM)-type three-stage model for Uruguayan data. The results show that ICTs play a bigger role for innovation and productivity in services than in manufacturing. At the same time, nontechnological innovations provide a more important contribution to firm productivity in the services sector than in the manufacturing sector.

JEL classification: O31, O32, D22, O38.

1. Introduction[1]

Throughout the world, empirical evidence has shown that innovation is an effective means of improving productivity, spurring economic growth, and raising living standards (Hall and Jones, 1999; Rouvinen, 2002; Hall, 2011). The earliest analysis of the impact of innovation on productivity (Griliches, 1979) focused mainly on the contributions of investment in research and development (R&D). In recent decades, the scope of the literature aimed at understanding

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the engines of productivity growth has broadened to include other types of investments. Today, information and communications technologies (ICTs) are widely recognized as one of the main drivers of global economic growth.

ICTs have the potential to affect economic growth and productivity both directly and indirectly. Productivity improvements in sectors that produce ICT goods or services contribute directly to the aggregate productivity of the economy proportionally to the size of the ICT sector (Gordon, 2000, 2012; Jorgenson *et al.*, 2002, 2008; van Ark *et al.*, 2008). More importantly, ICTs affect the productivity of the sectors in which these are used. Specifically, ICTs enable faster communication and information processing, ease internal coordination, facilitate decision-making, and reduce market failures associated with information asymmetries (Gilchrist *et al.*, 2001; Atrostic *et al.*, 2004; Arvanitis and Loukis, 2009; Cardona *et al.*, 2013). Firm-level research confirms that ICTs operate as an enabling factor for businesses to innovate and improve their performance, serving as a general-purpose technology (Bresnahan and Trajtenberg, 1995).

A variety of studies on developed countries find the impact of ICT investment on productivity to be greater than that for non-ICT investment (Brynjolfsson and Hitt, 1995, 2000; Brynjolfsson and Yang, 1996; Greenan and Mairesse, 2000; Brynjolfsson *et al.*, 2002). Similarly, the relationship between ICT and productivity at the firm level is generally positive (Black and Lynch, 2001; Greenan *et al.*, 2001; Bresnahan *et al.*, 2002; Bugamelli and Pagano, 2004; Castiglione, 2012). Evidence also shows that the contribution of ICTs toward productivity varies widely by country and industry.

This article focuses on understanding the determinants of investments in ICTs and in other innovation activities at the firm level and how the adoption of ICT and other innovation activities ultimately affects the technological (product and process) and nontechnological (organizational and marketing) innovation and productivity of Uruguayan firms in both the manufacturing and services sectors.

In the recent period, all indicators related to the diffusion and access of ICT in Uruguay showed great improvements. This is a direct consequence of public policies aimed at providing universal access to ICTs through a public telecommunication operator, and through the implementation of an ambitious plan that has delivered computers to all students enrolled in public primary schools, which is also starting to extend to secondary-level institutions (Plottier and Van Rompaey, 2013). With regard to the use of ICT by firms, the available evidence shows that the use of these technologies has increased, irrespective of the sector or region of the country. Nevertheless, micro, small, and medium firms are still lagging behind in terms of the levels of access and sophistication in the use of these technologies when compared with large firms (Lamschtein, 2013; Aboal *et al.*, 2015b). Marketwise, the country exhibits prices for the different types of Internet connections that are comparable with more developed regions and are well below the Latin American average (Galperín, 2013). Recently, a combination of increased budgetary allocations and institutional reforms, such as the creation of the National Research and Innovation Agency (ANII for its acronym in Spanish), has led to higher levels of R&D and innovation expenditure at the firm level. The ANII has put in place different programs directed toward innovation in firms (particularly in SMEs), while software and IT firms have become a sector heavily supported by a variety of instruments. In fact, between 2008 and 2012, almost a quarter of total ANII grants went to the IT and software sector.

This article provides several contributions to the literature. First, we assess the relative importance of investments in ICTs and all other innovation activities (R&D, acquisition of capital assets, engineering and industrial design, technology transfer and consulting, organizational design, and management and training) for innovation and productivity. As far as we know there are no previous papers that have done this at the firm level. We are aware of only a few recent papers that have focused on the relative importance of R&D and ICT at the firm level, but these have not taken into account all other innovation activities (Polder *et al.*, 2009; Hall *et al.*, 2012; Álvarez, 2016). R&D represents a small portion of the investment that most firms carry out with the objective of introducing innovations and improving productivity. Moreover, this broadened focus is especially relevant for developing countries where firms in general do little R&D, and for firms in the services sector that spend far less in R&D and more in other innovation activities compared with firms in the manufacturing sector (Aboal *et al.*, 2015a). In developing countries and particularly in LAC economies, firm innovation consists in incremental changes that have little or no impact on international markets and that are mostly based on imitation and technology transfer (e.g. acquisition of machinery and equipment and disembodied technology) (Anlló and Suárez, 2009; Navarro *et al.*, 2010). R&D is often prohibitively expensive, and it could require long timeframes (Navarro *et al.*, 2010).

Second, we set up and use a unified econometric framework based on a version of the CDM model (Crepón *et al.*, 1998) that helps to identify both similarities and differences of firms' innovation and productivity performance in the services and manufacturing sectors by using the same specification and data source. By doing so, we are able to highlight the common patterns and heterogeneities that exist in the adoption of ICT and other innovation activities and their effects on innovation and productivity.[2] The literature comparing the effects of ICT adoption in the firms in the service and manufacturing sectors is extremely scarce, and it includes the three papers mentioned in the previous paragraph, while the literature comparing the effects of all other innovation activities in both sectors is nonexistent.

Third, while most previous analyses of the link between ICTs, innovation, and productivity have focused on technological innovations (i.e. product and process innovations) or have not distinguished between technological and nontechnological innovations (i.e. "any innovation" informed by the firm), we explicitly consider the impact on nontechnological innovations, namely, organizational and marketing innovations. This is important because the investment in ICTs and other innovation activities could have a heterogeneous effect on both types of innovations and very little is known about this potential heterogeneity.

Finally, to date, the bulk of the literature on the effects of ICTs on innovation and productivity has focused on developed countries, while evidence from emerging economies is still scarce and dispersed. Most of the contributions from Latin America have centered on the diffusion and adoption determinants of ICTs (Basant *et al.*, 2006; Benavente *et al.*, 2011; Charlo, 2011; Calza and Rovira, 2011; Gutierrez, 2011; Gallego *et al.*, 2014; Grazzi and Jung, 2016), addressing the link between innovation and productivity without a robust identification strategy. Additionally, with the sole exception of Álvarez (2016), there is no evidence of the impact of ICTs' and other innovation activities' investment on the services sector's innovation and productivity in developing countries.

The emerging literature on innovation in the service industry shows that ICTs in general, and particularly new ICT applications, play a bigger role in innovation in comparison with the manufacturing industry (e.g. Polder *et al.*, 2009; Rybalka, 2009). In fact, innovation in the services sector compared with that in the manufacturing sector is predominantly nontechnological, less related to R&D, and closer to consumer demand (Licht and Moch, 1999; Tether, 2005; Tether and Tajar, 2008). From these observations, we can derive some *a priori* expectations for the empirical part of the article.[3] First, we would expect ICTs to have a more important role *vis-a-vis* other innovation activities for innovation and productivity in services sector firms than in manufacturing firms. Second, we expect ICTs to be more important than other innovations activities for nontechnological innovations. Finally, we could expect a more important role of nontechnological innovations *vis-a-vis* technological innovations for productivity in the services sector than in the manufacturing sector.

The remainder of the article is organized as follows: Section 2 provides a literature review. Section 3 describes the conceptual framework and presents the empirical strategy. Section 4 describes the data. Section 5 presents and discusses the results. Section 6 concludes.

2. Literature review

The earliest studies on the link between ICTs and productivity took an aggregate perspective with the intention of disentangling the so-called Solow paradox, according to which increasing investments in information technology (IT) do not necessarily lead to higher worker productivity. These contributions described the situation in the United States in the early 1990s. They subsequently looked at other developed regions, such as the European Union (EU), motivated by a need to understand whether, and to which extent, the United States–EU productivity gap was related to different patterns of ICT investment (van Ark *et al.*, 2003; Cette *et al.*, 2005).

The initial contributions took the form of growth accounting exercises.[4] Specifically, several studies (Oliner and Sichel, 1994, 2000; Gordon, 1999; Jorgenson, 2001; Jorgenson *et al.*, 2002, to name a few) find that in the 1990s,

2 Crespi and Zuñiga (2012), Aboal and Garda (2016) and Crespi *et al.* (2014) present specifications of the CDM model that include total innovation expenditures (and not only R&D) for a group of LAC countries. They find that firms that invest in knowledge are better able to introduce technological and nontechnological innovations, and those that innovate have higher labor productivity than those that do not. The focus of these works is not on ICT.

3 We prefer not to call them hypotheses, since we will not be testing them formally.

4 Different authors note the difficulties involved in measuring ICT at the aggregate level. Biagi (2013) mentions a few of the methodological problems involved. First, aggregate analyses do not prove causation between productivity and its determinants, thus reducing their usefulness in drawing policy implications. Second, growth accounting is normally based on the assumption of constant economies of scale and absence of externalities. These estimates might prove to be higher or lower than the actual effects in the presence of one or the other omitted aspects. Third, the methodology might fail to fully capture the quality improvements.

there was a positive relationship between ICTs and productivity in the United States. Several studies also find quite sizeable effects of ICT. For example, Oliner and Sichel (2000) find that capital deepening in ICTs and efficiency gains in the production of computers accounted for about two-thirds of the 1 percentage point step-up in productivity growth between the first and second halves of the 1990s. Similarly, Daveri (2003); Jorgenson *et al.* (2002); and Oliner and Sichel (2002) present results indicating that capital deepening in ICTs and total factor productivity in ICT-producing sectors together explain between 75% and 100% of the increase in labor productivity in the same period. While most of the research focuses on manufacturing, more recent efforts assess the impact on services. Bosworth and Triplett (2007) find a strong contribution of ICT in labor productivity growth in the US services sector.

Several studies (Colecchia and Schreyer, 2002; Crépon and Heckel, 2002; Oulton, 2002) extended the research beyond the United States. Colecchia and Schreyer (2002) applied the approach followed by Jorgenson *et al.* (2000) and Oliner and Sichel (2000) to nine Organisation for Economic Co-operation and Development (OECD) countries. Their results confirm that other developed countries also experienced higher growth rates due to the benefits arising from investment in ICTs. Although the effects have clearly been the largest in the United States, they find that ICTs contributed between 0.3 and 0.9 percentage points per year to economic growth during the second half of the 1990s. Oulton (2002) applies a modified growth accounting approach to the UK. The contribution of ICTs to the growth of gross domestic product (GDP) increased from 13.5% in 1979–1989 to 20.7% in 1989–1998. Using data on ICT investments from French firms' tax returns, Crépon and Heckel (2002) evaluated the contribution of ICTs to value-added growth via the accumulation of IT capital across all industries and the productivity gains in ICT-producing industries. They find that the contribution of the use of IT turns out to be significant around 0.3 of a point for an average annual value added growth of 2.6 percent during the period 1987–98.

The availability of sector- and firm-level data led to a second generation of studies that abandoned the growth accounting framework in favor of a more econometric approach (Biagi, 2013). These contributions have the potential to assess the effects of ICT investments on ICT-using sectors (the indirect effect) by looking at the role of complementary assets and their capacity to enable other types of innovation and investment. Thus, ICTs allow for substitution effects, triggering processes and organizational innovations (Black and Lynch, 2001; Bresnahan *et al.*, 2002; Hempell and Zwick, 2008, to name a few). At the same time, there is some evidence that previous innovation performance might help determine the potential use of ICTs (Hempell, 2002). In a similar vein, Cerquera and Klein (2008) argue that since adoption rates and capacity to reap the benefits of ICT differ from one firm to the next, ICTs might represent a source of firm heterogeneity that generates competitive advantages, affects firm strategies, and/or influences aggregate productivity growth. Specifically, they find that in the case of Germany, ICTs have a robust, positive impact on firm heterogeneity when ICTs are used intensively and jointly with specific ICT applications. Moreover, ICT-induced heterogeneity is shown to have a positive, albeit small, impact on the decision to invest in R&D personnel. In relation to sectorial evidence, Rybalka (2009) shows in the case of Norway that ICTs have a positive impact on firm labor productivity and show high complementarity with the use of highly skilled workers. The results also indicate considerable differences between firms in manufacturing and services sectors, and between firms in different service industries with respect to productivity effects of ICTs, non-ICTs, and human capital and with respect to the gain of joint use of ICTs and highly skilled workers. Hempell *et al.* (2004) show for German and Dutch firms of the services sector that the contribution of capital deepening in ICTs is raised when firms combine ICT use and technological innovations on a more permanent basis. In the case of LAC, Grazzi and Jung (2016) found a positive relation between ICT investment (in the form of broadband connectivity) and productivity, through an increased likelihood of innovation, and better resources for R&D. Similarly, Gutierrez (2011) found a positive and significant effect of ICT investments on labor productivity in Colombian manufacturing firms.

Another strand of research treats ICT as an input, both for the production function and, more importantly, for the knowledge production function. Based on the CDM model, these contributions enable potential biases due to simultaneity and selectivity that are to be accounted for. Polder *et al.* (2009), using Dutch data, extend the CDM model to include an equation for ICT as an enabler of innovation and organizational innovation as an indicator of innovation output. Specifically, they distinguish two types of innovation inputs: R&D expenditures and ICT investment. Both feed into a knowledge production function consisting of a system of three innovation output equations (product innovation, process innovation, and organizational innovation), which ultimately, feed into a productivity equation. By doing so, they find that ICT is more important for service than for manufacturing. The reverse is true for R&D. Álvarez (2016) found that ICTs relate positively to innovation and productivity in Chile. Of particular importance, ICT investment is found to be more important than R&D in the services sector. In fact, R&D is not a significant determinant of innovation in the service industry.

Hall *et al.* (2012) use an augmented version of the CDM in which they treat ICT in parallel with R&D as an input to innovation rather than simply as an input of the production function. By doing so, they are able to take into account the possible complementarities among different types of innovation activities. Their framework encompasses three groups of relationships. The first is the decision of whether and how much to invest in R&D. The second consists of a set of binary innovation outcomes during the previous three years. The investment decisions of firms with respect to R&D and physical capital presumably drive these outcomes. The element of novelty is the inclusion of ICT expenditure at this stage to explain innovation activity. The final equation is a conventional labor productivity regression that includes the innovation outcomes. Their contribution is based on a large unbalanced panel data sample of Italian manufacturing firms in the 1995–2006 period.

3. Conceptual framework and empirical strategy

We extend the frameworks proposed by Griliches (1979), Crépon *et al.* (1998) and Hall *et al.* (2012) for the purpose of adapting them to the specificities of firms in the services sector, particularly those in Latin America, while paying special attention to ICT investments. Our framework adds some ingredients taken from Crespi and Zuñiga (2012) and Aboal and Garda (2016) as we also consider other innovation activities beyond R&D into our estimates. For this, we will exploit data from different innovation surveys.

The original contribution of Griliches (1979) has as a starting point a production function where one of the key inputs is R&D. Crépon *et al.* (1998) have a production function where the key variable of interest is the innovation output (proxied by patents per employee). In our case, the production function is specified as:[5]

$$y_i = c + \pi_1 k_i + \pi_2 l_i + \pi_3 h_i + \pi_4 INNp_i + v_i \tag{1}$$

Sometimes, alternatively, we will be estimating the following equation:

$$y_i = c + \pi_1 k_i + \pi_2 l_i + \pi_3 h_i + \pi_4 ICTp_i + \pi_5 IInictp_i + v_i \tag{1'}$$

where y is sales per worker, k is physical capital per worker, l is the number of workers (our firm size variable), h is a measure of human capital (number of professionals and technicians per worker), $INNp$ is the predicted innovation output that results from equation (2), $ICTp$ is predicted investment in software and hardware per worker (from equation (3)), $IInictp$ is the predicted investment in other innovation activities (from equation (3)), c is a constant, π_s are parameters, and v_i is a disturbance term. All the variables are expressed in logarithms with the exception of $INNp$. In addition, international standard industrial classification (ISIC) two-digit dummies are included in all regressions.

Following the previously cited works, we will model explicitly the innovation outcome, or the production function, of innovations. We will distinguish between technological (product and process) and nontechnological (organizational or marketing) innovations. This is conceptually very relevant, since we know that firms in the services sector have a greater propensity to introduce nontechnological innovations, and that innovation in services is, for example, less dependent on formal R&D than innovation in manufacturing (Aboal and Garda, 2016). In other words, firms in the services sector innovate differently, and the innovation production function is different across sectors.

The *innovation output* equation, sometimes also called *knowledge production function*, is:

$$INN \equiv \begin{pmatrix} TI_i \\ NTI_i \end{pmatrix} = \mathrm{ICTIp_i}\gamma_0 + \mathrm{IInictp_i}\gamma_1 + \mathrm{x_i}\delta + \mathrm{u_i} \tag{2}$$

where TI is a dummy indicating technological innovation and NTI is a dummy for nontechnological innovation, $ICTIp$ is the predicted investment in software and hardware, and $IInictp$ is the predicted investment in all other innovation activities. These last two variables will be predicted from Heckman regression (see next equations).

5 This formulation can be obtained from a Cobb–Douglas production function with capital, labor, and human capital and by dividing both sides by labor and taking logs. The innovation output enters in the equation as affecting the per worker output.

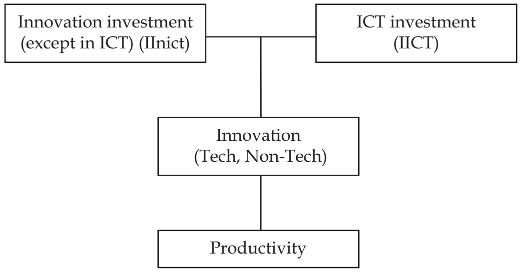

Figure 1. ICT and other innovation activities (investments, innovation, and productivity).

γ_0 and γ_1 are diagonal matrices of parameters and δ is a block diagonal matrix of parameters, x is a block diagonal matrix of determinants of innovation production, and u is the error vector. As additional control variables (in the x matrix), we are including the logarithm of the number of employees in the firm (firm size), a dummy indicating if the firm is an exporter, a dummy indicating if more than 10% of the firm's capital is foreign-owned, and finally the log of the ratio of professionals and technicians in the workforce. Industry dummies are also included in all regressions. These sets of variables are similar to the ones used in previous papers that used the CDM model in Latin America (Crespi and Zuñiga, 2012; Álvarez, 2016), except for the human capital variables that we are including here. A biprobit model will be estimated at this stage.

The decision to engage in and the amount invested in innovation activities (on ICT and IICT or in all of the other innovation activities, IInict) will be modeled independently with a Heckman model for each variable.

The firm first decides whether to invest in innovation activities, and then decides how much to invest. The *innovation decision* equation could be expressed as follows:

$$\begin{aligned} ID_i = 1 \text{ if } \quad w_i\alpha + \epsilon_i > c \\ ID_i = 0 \text{ if } \quad w_i\alpha + \epsilon_i \le \text{c} \end{aligned} \tag{3}$$

where ID is the innovation decision binary variable, which is 1 for firms that decide to invest in innovation activities and 0 for firms that do not (it could be either in ICT or in all other activities); w is the vector of explanatory variables that determine the decision; α is the vector of parameters; ϵ is the error term; and c is the threshold level that determines whether the firm decides to invest in innovation. The vector of variables is the same as that contained in x with the addition of dummy variables. These variables indicate if the firm has obtained patent protection; if the firm has received public financial support for innovation activities; if the firm cooperates with other firms to carry out R&D activities; or if the firm considers market, scientific, or public sources of information important for the innovation activities.

A second equation will model the magnitude or intensity of innovation activities carried out by firms (on ICTs or on all the other activities). The dependent variable in this case is the logarithm of the actual innovation investment per employee (in IICT or IInict). As for the explanatory variables, we assume that the variables that affect the decision process of engaging in certain innovation activities also determine the magnitude of that activity, but because we are using innovation expenditure per employee, the variable size (number of employees) is not included in this equation (this exclusion will also allow the identification of the first equation). Implicitly, since our dependent variable is (log of) innovation expenditure per employee, we are assuming that innovation expenditure is strictly proportional to size. In the equation for log ICT investment we are excluding the variable cooperation in R&D, assuming that this variable should have only a direct impact on R&D investment and therefore only on IInict. This assumption will serve as an identification assumption.

Accordingly, the equation for *innovation effort (or investment)* would be:

$$\begin{aligned} I_i = z_i\beta + e_i \qquad & \text{if } ID_i = 1 \\ I_i = 0 \qquad & \text{if } \quad ID_i = 0 \end{aligned} \tag{4}$$

where I is the magnitude of the investment (or the log innovation investment per employee), z is the vector of explanatory variables, β is the vector of parameters, and e is the disturbance term.

Table 1. Contribution of the service sector to GDP and employment in Uruguay *(average, 2005–2009)*

	GDP	Employment
Subsectors as percent of services sector		
Electricity, gas, and water[a]	3.5	1.2
Retail	18.7	27.6
Hotels and restaurants[a]	4.6	3.9
Transport and communication[a]	12.9	8.1
Financial intermediation	7.9	2.4
Real estate, renting, and business[a]	23.4	9.7
Public administration and defense	8.5	9.7
Education	6.3	8.1
Activities related to human health[a]	8.1	10
Professional services and domestic household services	6.1	19.2
Sectors covered by SIS[b]	52.5	33
Service sector/total economy	59.2	73.5

Sources: National Bureau of Statistics and Central Bank of Uruguay.
[a]Included in innovation surveys.
[b]Including real state.

For the second variable (innovation investment) to be observable, the first one (innovation decision) has to surpass the stated threshold. Otherwise, no investment would occur, and there would be no magnitude or intensity to measure.

Figure 1 illustrates the sequential structure of the model. First, firms decide whether to invest and how much to invest in ICTs and other types of innovation activities not related to ICTs (R&D, acquisition of capital assets, engineering and industrial design, technology transfer and consulting, organizational design, and management and training). Second, firms produce innovations. The key factors in this knowledge production function are the level of investment in ICTs and other innovation activities. Third, the innovation and other production factors affect the level of productivity of firms. As discussed in the introduction, we include all innovation expenditures, and not only the expenditure on R&D. One of the reasons to go beyond R&D is that firms in the services sector tend to generate innovations without the use of formal R&D. More importantly, there is no reason not to include other innovation investments, since in principle any investment in innovation activities can generate innovations. One of the important features of our model is the separate treatment of technological and nontechnological innovations, albeit in a common framework. This is especially relevant for analyzing innovation in service firms.

4. Data and descriptive statistics

The services sector is one of the major contributors to output and employment in Uruguay. In the period 2004–2009, it accounted for ~60% of GDP and employed more than 70% of the total workforce. Both employment and output of the services sector are concentrated in a few subsectors (retail, communications, and real estate, renting, and business services). Here, we are exploiting different waves of innovation surveys for both the manufacturing and services sectors. Service innovation surveys (SIS) in Uruguay do not cover the universe of services. However, the weight of the subsectors considered here is significant in terms of output and employment, representing more than 50% of the output and 33% of employment in the sector (see Table 1).

The subsectors covered by the SIS in Uruguay are the following (ISIC Rev.3): electricity, gas, steam and hot water; collection, purification and distribution of water; hotels and restaurants; land transport; water transport; air transport; auxiliary transport activities and travel agencies; post and telecommunications; rental of machinery equipment, personal effects and household goods; informatics and related activities; R&D; business services; and activities related to human health. ANII chose these subsectors based on the following two criteria: first, that knowledge-intensive services should be well represented in the sample, in particular knowledge-intensive services; second, the SIS should include subsectors considered important for the economic development of the country.

Table 2. Descriptive statistics of variables included in regressions

	Mean	S.D.	Min	Max
Manufacturing				
Technological innovation (1)	0.38	0.49	0.00	1.00
Nontechnological Innovation (2)	0.20	0.40	0.00	1.00
Productivity (3)	1648.91	2491.05	56.33	25712.73
Non-ICT innovation expenditure (4)	21.77	59.48	0.00	534.11
ICT innovation expenditure (5)	1.47	7.31	0.00	153.05
No investment in ICT (6)	0.81	0.39	0.00	1.00
Firm size (7)	3.63	1.23	0.00	7.75
Exporter (8)	0.38	0.48	0.00	1.00
Foreign ownership (9)	0.11	0.32	0.00	1.00
Patent (10)	0.02	0.15	0.00	1.00
Cooperation in R&D (11)	0.07	0.25	0.00	1.00
Market sources of information (12)	0.85	0.36	0.00	1.00
Scientific sources (13)	0.26	0.44	0.00	1.00
Public sources (14)	0.73	0.44	0.00	1.00
Public support (15)	0.04	0.20	0.00	1.00
h (Share skilled labor) (16)	0.11	0.15	0.00	1.00
h = 0 (17)	0.25	0.43	0.00	1.00
k (18)	0.64	1.55	0.00	21.00
Services				
Technological innovation(1)	0.31	0.46	0.00	1.00
Nontechnological innovation (2)	0.24	0.43	0.00	1.00
Productivity (3)	1118.78	2191.69	18.00	31936.16
Non-ICT innovation expenditure (4)	11.69	45.04	0.00	536.07
ICT innovation expenditure (5)	3.17	20.28	0.00	368.75
No investment in ICT (6)	0.79	0.40	0.00	1.00
Firm size (7)	3.71	1.40	0.00	9.21
Exporter (8)	0.14	0.35	0.00	1.00
Foreign ownership (9)	0.10	0.30	0.00	1.00
Patent (10)	0.02	0.13	0.00	1.00
Cooperation in R&D (11)	0.03	0.17	0.00	1.00
Market information sources (12)	0.87	0.34	0.00	1.00
Scientific sources (13)	0.32	0.47	0.00	1.00
Public sources (14)	0.71	0.46	0.00	1.00
Public support (15)	0.02	0.14	0.00	1.00
h (Share skilled labor) (16)	0.23	0.28	0.00	1.00
h = 0 (17)	0.25	0.43	0.00	1.00
k (18)	0.85	3.24	0.00	62.04

Notes: (1) Product or process innovation; (2) organizational or marketing innovation; (3) sales per employee at the end of year of survey in local currency at constant prices; (4) R&D expenditures and other innovation expenditures such as design, installation of machinery, industrial engineering, and embodied and disembodied technology (capital and machinery, patents, patent and trademark licensing, disclosures of know-how, and other technological services) with the exception of ICT investment, and design, marketing, and training per employee in local currency at constant prices; (5) expenditures on software, hardware, and computer services in local currency at constant prices; (6) share of firms that do not report investment in ICT; (7) log of the number of employees; (8) share of firms that export; (9) share of firms with foreign capital greater than 10%; (10) share of firms that applied for a patent in the survey period; (11) share of firms that cooperated in R&D on innovation activities; (12) share of firms that indicated market sources (suppliers, clients, competitors, consulting firms, experts) as very important or important for innovation projects; (13) share of firms that indicated scientific sources (universities, public research center, or technological institutions as very important or important for innovation projects; (14) share of firms that indicated public sources (journals, patents, magazines, expositions, associations, databases, Internet) were very important or important for innovation projects; (15) share of firms that received public financial support for innovation; (15) share of firms that applied for one or more patents; (16) log of share of skilled employment (professional and technicians over total employees); (17) share of firms with no skilled employment; and (18) log of total fixed assets over employees. Year-beginning survey.

We use two waves of SIS available in Uruguay (covering the periods 2004–2006 and 2007–2009) and the last two available Manufacturing Innovation Surveys (MIS) (2004–2006 and 2007–2009), which include all manufacturing subsectors. The data on these surveys are collected in parallel with the Economic Activity Survey (EAS), using the

Table 3. Selection equation: average marginal effects

Variables	Manufacturing		Services	
	(1) P(IInict > 0)	(2) P(ICTI > 0)	(3) P(IInict > 0)	(4) P(ICTI > 0)
L (=size)	0.104***	0.101***	0.075***	0.084***
	(0.009)	(0.004)	(0.005)	(0.003)
D(Exporter)	0.019	−0.002	0.090***	0.019
	(0.017)	(0.017)	(0.031)	(0.020)
D(Foreign_owned)	0.016	−0.028	0.017	0.022
	(0.032)	(0.025)	(0.037)	(0.038)
D(Patent)	0.310***	0.175***	0.407***	0.100*
	(0.100)	(0.029)	(0.124)	(0.053)
D(PubSupport)	0.540***	0.060*	0.626***	0.116**
	(0.114)	(0.033)	(0.124)	(0.055)
D(Coop_RD)	0.378***		0.345***	
	(0.042)		(0.062)	
h	0.280**	0.274***	0.184***	0.154***
	(0.112)	(0.059)	(0.070)	(0.040)
D(h = 0)	−0.102***	−0.040*	−0.090**	−0.048**
	(0.033)	(0.021)	(0.041)	(0.021)
D(Market info)	0.101***	0.026	0.134***	0.096**
	(0.035)	(0.025)	(0.045)	(0.047)
D(Scientific info)	−0.072**	−0.046**	−0.051*	−0.01
	(0.030)	(0.018)	(0.028)	(0.024)
D(Public info)	0.029	0.069**	0.02	−0.001
	(0.028)	(0.030)	(0.032)	(0.010)

Robust standard errors in parentheses. Delta method.
$^{***}P < 0.01$,
$^{**}P < 0.05$,
$^{*}P < 0.1$. All regressions include two-digit ISIC dummies.

same sample and statistical framework.[6] The final numbers of firms included after cleaning the databases were 1868 firms in the services sector and 1727 firms in manufacturing.[7]

Both surveys have been matched with the EAS to obtain the level of firm's fixed assets needed for the productivity equation. To avoid endogeneity problems associated with the capital variable, we use this variable at the beginning of the survey period. All other variables used in the empirical exercises come from the SIS or the MIS. The matching with the EAS was not without loss. Due to sampling frame changes and registration problems, we lose a significant number of firms. When using the capital per worker variable (i.e. after matching with the EAS) the sample is reduced to 1093 firms in the services sector and 1209 in manufacturing sector.

All the empirical exercises that we will perform below use pooled cross-section data.

Table 2 presents some descriptive statistics of the sample, both for manufacturing and services sector firms. Overall, we do not find great differences in the innovative behavior of the firms operating in one sector or the other; around one-third of the firms claim to have introduced technological innovation, and around a quarter nontechnological innovation. Consistent with the existing evidence, manufacturing firms are more likely than services sector

6 All firms with more than 49 workers are required to be included. Units with 20–49 employees and with fewer than 19 workers are selected using simple random sampling within each economic sector at the ISIC two-digit level up to 2005. Since then, random strata are defined for units with fewer than 50 workers within each economic sector at the ISIC 4-digit level

7 Firms with missing information on sales or employment were excluded. Also excluded were the percentiles 1 and 99 of productivity and the percentile 99 of innovation investment per employee.

firms to have introduced product or process innovation, while the opposite is true for organizational or marketing innovation. Manufacturing firms are more likely to have engaged in cooperative ventures for the development of R&D projects. Although the average size of firms in the two sectors is similar, the manufacturing sector is more productive.

With respect to ICT investment and the prevalence of nontechnological innovation, we observe that a higher proportion of services sector firms report some expenditure on ICT items (software, hardware, or computer services), allowing for an ICT expenditure intensity more than double of that for manufacturing. Similarly, services sector firms are endowed with a higher proportion of skilled personnel. From the point of view of policy intervention, the data show that the proportion of firms that have been involved in some sort of program aimed at promoting innovation is rather small; it is evident that manufacturing sector firms have received more support than services sector firms.

5. Results

5.1 Investment in ICT and other innovation activities

In Table 3 we can see the results from the probit estimation of the investment decision in ICTs and other innovation activities, for both manufacturing and services sectors. The first thing to note is the positive and consistent correlation between firm size and the decision to invest in all four regressions. This is one of the most consistent findings in the literature: firm size is relevant for investment in innovation. One way of interpreting this finding is that there are some fixed costs, particularly related to R&D and fixed assets investments (e.g. labs), involved in introducing innovations, which larger firms can spread out over more units of output. An additional fact related to firm size is worth noting: size seems to be less relevant for the services sector than for the manufacturing sector. This may be because the services sector firms use less formalized processes to produce innovations and therefore are less subject to economies of scale in their production, implying that size is less relevant for the decision of investing in innovation activities.

The dummy variables Exporter and Foreign-owned do not seem to be very relevant for the decision to invest in innovation activities. The variable Exporter, a proxy for the intensity of the links with external markets, is only significant for the investment in other innovation activities in the case of services sector firms.

The dummy Patent, which takes value 1 when the firm applied for a patent, is a proxy of past innovation efforts from firms. Even though this is an imperfect proxy, since few firms apply for patents (2.3% of manufacturing firms and 1.3% of services sector firms), it is correlated with the decision to invest in innovation activities, in both ICTs and other activities, and in both the manufacturing and services sectors. The point estimates of this variable for other innovation activities is larger than those for ICT. This fact suggests that the decision to invest in ICTs requires less accumulated knowledge than other types of investments. This could be because ICT investment requires less noncodified knowledge. The investment in other innovation activities includes, for example, R&D investment, which is complex to carry out without previous accumulated knowledge.

The dummy PubSupport, which takes value 1 when the firm receives public financial support for innovation activities, is a variable that is positively correlated with the decision to invest in other innovation activities, but it seems to be less relevant in the decision to invest in ICTs. However, it seems to be more important for ICTs in the services sector than in the manufacturing sector. One hypothesis is that it is likely that public support has been directed more toward other innovation activities than toward ICTs.

The cooperation between firms in R&D activities (the dummy Coop_RD) is one of the variables that is most consistently positively associated with the decision to invest in innovation activities. The coefficients are similar across sectors, but not across innovation activities. They are smaller in the case of ICTs, indicating that ICT activities can be done relatively independently of the cooperation of other firms in R&D activities.

The variable human capital (share of professionals and technicians in the workforce) is important in investment decision equations for both manufacturing and service sectors, but the coefficients are larger for manufacturing firms. On the other hand, the absence of skilled labor (i.e. $h = 0$) clearly conspires against investment in innovation activities (in ICTs and others). Only market sources of information (for suppliers, clients, competitors, consulting firms, experts) are consistently positively associated with the decision to invest (except in the case of ICTs in the manufacturing sector). Public and scientific sources of information do not seem to be in general positively correlated with the decision to invest. In fact, in some cases, significant negative signs are found.

In Table 4 the results for the innovation effort (or innovation investment) are shown. Four variables are ones that are usually associated with greater investment in innovation activities across sectors and across types of investment: Coop_RD, h, $D(h = 0)$ and D(Market info). When comparing the point estimates, human capital appears to be more important for the level of ICT investment than for the level of investment in other innovation activities.

Table 4. Level of investment equations

Variables	Manufacturing		Services	
	(1) IInict	(2) ICTI	(3) IInict	(4) ICTI
D(Exporter)	0.119	−0.0520	0.294	0.154
	(0.131)	(0.225)	(0.226)	(0.307)
D(Foreign_owned)	−0.193	0.456**	0.0401	1.072***
	(0.186)	(0.183)	(0.227)	(0.312)
D(Patent)	−0.274	1.216***	0.503*	0.889
	(0.320)	(0.347)	(0.260)	(0.633)
D(PubSupport)	0.490	0.855**	0.943	0.747
	(0.326)	(0.431)	(0.689)	(0.809)
D(Coop_RD)	0.467**		0.937**	
	(0.187)		(0.373)	
h	1.791**	4.582***	1.955***	3.105***
	(0.713)	(1.058)	(0.446)	(0.903)
D(h = 0)	0.604***	−0.153	−0.683**	−0.856**
	(0.198)	(0.323)	(0.280)	(0.420)
D(Market info)	0.0238	0.590*	0.489**	0.878**
	(0.191)	(0.340)	(0.222)	(0.376)
D(Scientific info)	−0.0556	−0.392**	−0.138	−0.162
	(0.240)	(0.184)	(0.128)	(0.416)
D(Public info)	−0.0269	0.576	0.183**	0.0316
	(0.140)	(0.402)	(0.0903)	(0.201)
Constant	2.155***	−7.071***	−1.237**	−11.88***
	(0.611)	(0.541)	(0.534)	(0.910)
athrho	−0.243	1.545***	0.595***	2.128***
	(0.214)	(0.185)	(0.174)	(0.0974)
lnsigma	0.515***	0.911***	0.648***	1.310***
	(0.0385)	(0.0737)	(0.0671)	(0.0551)
Observations	1727	1727	1868	1868
Log likelihood	−2211	−2211	−1285	−1285

Robust standard errors in parentheses.
***$P < 0.01$,
**$P < 0.05$,
*$P < 0.1$. All regressions include two-digit ISIC dummies.

There are other variables that introduce some differences across sectors or types of innovation activities. Foreign-owned firms (i.e. firms with foreign capital greater than 10%) invest more in ICTs, particularly in the services sector. Manufacturing sector firms that have applied for patents invest more in ICTs.

In the appendix, in Table A2, we show the marginal effects of different variables on the expected log investment, conditional on investment being positive. These marginal effects involve the direct effects summarized in Table 4 and indirect effects coming from the selection equation.

5.2 Technological and nontechnological innovation

The main objective of this subsection is to analyze the roles of ICTs and investments in other innovation activities in the production of technological and nontechnological innovations in manufacturing and service sectors. As discussed in the methodology section, the idea is to introduce the prediction of the investment in ICTs and other innovation activities as an input of the innovation production function. The prediction of these variables (i.e. IInict_pred and ICTI_pred) is highly correlated services (0.8), and this could be a problem. Therefore, we will also run an alternative regression for services introducing the observed ICT investment (ICTI) and a dummy that takes value 1 when there is no investment in ICT (D(No ICTI)) and 0 in the other case instead of ICTI_pred. These variables are not much

Table 5. Technological and Nontechnological innovation

Variables	Manufacturing				Services			
	(1) Tech	(2) Non-Tech	(3) Tech	(4) Non-Tech	(5) Tech	(6) Non-Tech	(7) Tech	(8) Non-Tech
IInict_pred	2.144***	0.468**	2.442***	0.552**	1.156***	0.560***	1.045***	0.535***
	(0.359)	(0.234)	(0.314)	(0.215)	(0.205)	(0.183)	(0.137)	(0.110)
ICTI_pred	0.672***	0.432***			0.006	0.246		
	(0.081)	(0.093)			(0.202)	(0.187)		
ICTI			−0.035	0.0906**			0.103***	0.002
			(0.039)	(0.045)			(0.030)	(0.031)
D(No ICTI)			−1.255***	−1.670***			−1.772***	−1.340***
			(0.166)	(0.175)			(0.119)	(0.129)
L (=Size)	0.340***	0.304***	0.271***	0.265***	0.185***	0.214***	0.163***	0.157***
	(0.038)	(0.035)	(0.048)	(0.042)	(0.028)	(0.030)	(0.027)	(0.037)
D(Exporter)	−0.120	−0.178**	−0.205**	−0.294***	−0.074	0.056	−0.084	0.058
	(0.075)	(0.090)	(0.097)	(0.087)	(0.112)	(0.100)	(0.143)	(0.113)
D(Foreign_owned)	0.072	−0.159	0.388**	−0.031	−0.196	0.030	−0.385***	0.246***
	(0.152)	(0.126)	(0.153)	(0.140)	(0.230)	(0.239)	(0.125)	(0.089)
H	−6.202***	−2.021***	−3.866***	(0.507)	−1.838***	−1.563***	−1.793***	−0.957***
	(0.817)	(0.591)	(0.604)	(0.526)	(0.503)	(0.363)	(0.346)	(0.293)
D(h = 0)	−1.497***	−0.604***	−1.764***	−0.701***	0.455***	0.317**	0.484***	0.177
	(0.254)	(0.193)	(0.192)	(0.149)	(0.139)	(0.138)	(0.144)	(0.123)
Constant	−2.235**	−0.257	−5.728***	−1.520***	−0.54	1.28	0.976***	−0.17
	(0.919)	(0.856)	(0.847)	(0.583)	(2.189)	(1.980)	(0.245)	(0.214)
Athrho	0.529***		0.333***		0.554***		0.276***	
	(0.046)		(0.059)		(0.046)		(0.054)	
Observations	1727		1727		1868		1868	
Log likelihood	−1581		−1431		−1561		−1561	

Bootstrapped standard errors in parentheses.
***$P < 0.01$,
**$P < 0.05$,
*$P < 0.1$. All regressions include two-digit ISIC sector dummies.

correlated with IInict_pred. The correlation for the manufacturing case is not high (0.29); therefore, it is not a problem to include simultaneously IInict_pred and ICTI_pred in the biprobit regression. In any case and for completeness we are presenting the results using ICTI and D (No ICTI) in columns (3) and (4).

Columns (1)–(2) and (5)–(6) of Table 5 show the results using IInict_pred and ICTI_pred, and Columns (3)–(4) and (7)–(8) using ICTI and D(No ICTI) instead of ICTI_pred. Columns (1) and (2) show that for the manufacturing sector, both IInict_pred and ICTI_pred are highly significant in the technological and nontechnological innovation equations.[8] In Table 6 we show the average marginal effect for these focal variables on the probability of different outcomes. From Table 6 we can conclude that both types of investments increase the probability of introducing technological innovation alone and also together with nontechnological innovation. The investment in other innovation activities seems to have a bigger impact than the investment in ICTs.

As noted before, the correlation between IInict_pred and ICTI_pred is very high in the case of the service sector. This means that these two variables contain similar information. When introduced together in the biprobit analysis, the predicted investment in ICTs is not significant (Column 5). The alternative estimation that is less prone to the problems coming from the high correlation between IInict_pred and ICTI_pred (Columns 7 and 8) shows that

8 In regressions not reported here we have also introduced and interaction term IInict_pred × IICT_pred, this term tends to be non-significant in the regressions, and moreover it exhibits a very high correlation with IICT_pred. Therefore, we decided not to report these results

Table 6. Average marginal effects for probability of different innovation outcomes

	P(Tech = 1 and Non-Tech = 0)		P(Tech = 0 and Non-Tech = 1)		P(Tech = 1 and Non-Tech = 1)	
	(1)	(2)	(3)	(4)	(5)	(6)
Services						
IInict_pred	0.165***	0.131***	−0.022	−0.001	0.174***	0.122***
ICTI_pred	−0.029		0.036		0.031	
ICTI		0.018***		−0.007		0.007**
D(No ICTI)		−0.180***		−0.054***		−0.249***
Manufacturing						
IInict_pred	0.421***	0.455***	−0.085***	−0.072***	0.200***	0.185***
ICTI_pred	0.090***		0.001		0.105***	
ICTI		−0.018		0.009*		0.009*
D(No ICTI)		−0.068		−0.081***		−0.261***

***$P < 0.01$,
**$P < 0.05$,
*$P < 0.1$. Average marginal effects for the focal variables, using the estimations of Table 5. Columns (1), (3), and (5) use the estimations of Columns (1)–(2) and (5)–(6) of Table 5. Columns (2), (4), and (6) use the estimations of Columns (3)–(4) and (7)–(8) of Table 5.

Table 7. Productivity equation

Variables	Manufacturing			Services		
	(1) Productivity	(2) Productivity	(3) Productivity	(4) Productivity	(5) Productivity	(6) Productivity
IInict_pred	0.121	0.137		−0.022	0.130**	
	(0.112)	(0.113)		(0.082)	(0.051)	
ICTI_pred	0.045			0.159***		
	(0.050)			(0.057)		
ICTI		0.0811***			0.0940***	
		(0.024)			(0.021)	
D(No ICTI)		−0.400***			−0.528***	
		(0.109)			(0.111)	
P(Tech = 1 and Non-Tech = 1)			−1.462***			1.196***
			(0.344)			(0.281)
P(Tech = 1 and Non-Tech = 0)			1.252***			0.607
			(0.332)			(0.583)
P(Tech = 0 and Non-Tech = 1)			−5.862***			4.187***
			(1.251)			(0.762)
L (=size)	0.225***	0.234***	0.300***	−0.011	0.024	−0.139***
	(0.032)	(0.032)	(0.054)	(0.021)	(0.018)	(0.034)
k	0.196***	0.196***	0.187***	0.0689**	0.0651**	0.0647**
	(0.053)	(0.061)	(0.048)	(0.032)	(0.032)	(0.028)
h	0.118**	0.120***	0.195***	0.229***	0.244***	0.276***
	(0.047)	(0.043)	(0.036)	(0.039)	(0.032)	(0.028)
D(h = 0)	−0.605***	−0.628***	−0.941***	−0.826***	−0.879***	−0.885***
	(0.163)	(0.124)	(0.166)	(0.163)	(0.141)	(0.113)
Constant	12.77***	12.79***	13.09***	14.66***	13.46***	13.09***
	(0.457)	(0.397)	(0.201)	(0.557)	(0.123)	(0.171)
Observations	1209	1209	1209	1093	1093	1093
R-squared	0.311	0.317	0.334	0.434	0.446	0.446

Bootstrapped standard errors in parentheses.
***$P < 0.01$,
**$P < 0.05$,
*$P < 0.1$. All regressions include two-digit ISIC dummies. The predicted probabilities P(Tech = 1 and Non-Tech = 1), P(Tech = 1 and Non-Tech = 0), and P(Tech = 0 and Non-Tech = 1) come from the biprobit models expressed in Columns (1)–(2) and (5)–(6) of Table 4.

the level of investment in ICTs is correlated with technological innovations in services (but not with nontechnological innovations). However, the absence of ICT investments conspires against both technological and nontechnological innovations. Other innovation investments are relevant for both types of innovations. The marginal effects on the different probabilities reported in Table 6 show that the investment in ICTs and in other innovation activities increases the probability of technological innovations alone and also together with nontechnological innovations.

An interesting fact is that the probability of introducing nontechnological innovations is not increased by the investment in innovation activities (in fact in some cases it is reduced) (see Column 2 of Table 6). This could imply that nontechnological innovations require less formal processes to be generated, and therefore, do not require investments in innovation activities.

With respect to the other control variables, size continues to be a very relevant variable. The other variables' additional contribution (i.e. in addition to their indirect contribution through the innovation investments) to the increase in the probability of introducing technological and nontechnological innovations is not clear across industries and types of innovations. Note that the variables IInict_pred and ICTI_pred already contain the indirect effect of these variables coming from the previous stage. In fact, this could explain the negative sign of some of these variables.

5.3 Productivity

In this section, we estimate three versions of the labor productivity equation with alternative proxies of innovation and ICT investment. In Columns (3) and (6) of Table 7, we estimate the first equation proposed in the methodological section. In these regressions, we are using the predicted probability of introducing technological, nontechnological and both as proxies for different types of innovation outcomes. In the services sector, nontechnological innovation and the combined strategy of technological and nontechnological innovation have a positive impact on productivity. Technological innovation has no impact. For the manufacturing sector, only technological innovation has a positive impact on innovation; the other configurations have a negative impact. Note that we are measuring the contemporaneous effect of these variables. Innovation, and particularly organizational innovation, that is part of nontechnological innovation, could be especially disruptive in the short run, generating a negative impact on productivity.

When we use only the predicted investment in innovation activities in the regressions (Columns (1) and (4)), we find that ICT investment only increases productivity in the case of service firms. This result could be related to the positive correlation between IInict_pred and ICTI_pred. Therefore, in Columns (2) and (5), we use the observed ICT investment and a dummy capturing those firms that do not invest in ICTs as a replacement of ICTI_pred. From this exercise, we can see that investments in both ICT variables and all other innovation activities are positively associated with higher productivity in the case of services, while only investment in ICT is positively associated with higher productivity in the case of manufacturing firms. The impact of ICT on productivity is similar across sectors. Interestingly, the absence of investment in ICT is associated with lower levels of productivity in both sectors.

The variable size (or labor) is positive in the case of manufacturing firms, implying economies of scale in the production of these goods.[9] In services, there seem to be constant returns to scale (except in the case of the last regression). The coefficients of the variables k and h are significant and positive for both manufacturing and services sector firms, indicating that physical and human capital are relevant for labor productivity in both types of goods. The absence of skilled human capital (i.e. $D(h=0)=1$) is associated with lower productivity in both service and manufacturing sectors.

5.4 Discussion

In this section, we discuss the previous section's results in the light of the received literature and what it says with respect to the hypothesis stated in the article's introduction. The results will be compared with the received literature using a similar methodological framework. In particular we will focus on papers that use the CDM model. This implies that we will not be comparing our results with the large range of literature that directly estimates production functions by including ICTs without any reference to the innovation channel.

9 Constant returns to scale in L, K and H (the level variables) imply that the coefficient of L in the per capita productivity equation must be 0. Positive values imply increasing returns to scale.

Hall *et al.* (2012) compare the impacts of R&D and ICTs on innovation and productivity using a CDM-type model and data for manufacturing firms. Hall *et al.* (2012) did not analyze the heterogeneity between manufacturing and service and focus on R&D instead of a broader measure of investment in alternative innovation activities as we did. Investment in R&D enters as a predicted value in the innovation and productivity regressions, while investment in ICTs is entered as an observed value. They find that a dummy indicating no ICT investment is highly significant to explain innovation (they are using in the main estimations a dummy indicating "Any Innovation"); however, the intensity of ICT investment is only significant at 5% and 10% in the two regressions performed. The predicted value of R&D is highly significant to explain innovation. In their paper's appendix, they also explore the impact of R&D and ICTs on different types of innovation (product, process, organizational). The results are similar: predicted R&D investment is highly significant and positively correlated with all the types of innovations, the dummy indicating no ICT is consistently negative and significant, while the variable measuring the intensity of ICT investment is not always significant. These results are similar to the ones we have found. What seems to matter the most for innovation is to have a positive investment in ICTs. The amount invested does not necessarily increase the probability of all types of innovations and it tends to be less significant in the regressions than in the dummy "no ICT." Similar to what they found for R&D, in our case, the investment in other innovation activities is highly significant and consistently positively associated to more innovation.

With respect to labor productivity, they run regressions including only the predicted innovation from previous stage, only R&D and ICT and both. In all the regressions reported, they find that the intensity of R&D and ICT has a positive effect, and the absence of investment in ICT has a negative effect. Innovation alone has a positive effect. However, when introduced simultaneously with both types of investments, it loses significance and even changes its sign (probably due to multicollinearity problems). We have similar results with the variables investment in ICTs and with the dummy for no investment in ICTs. However, the variable IInict is not always significant. Moreover, in our case some of the variables that are proxies for some types of innovation appear to be negatively correlated to productivity in the manufacturing sector in the short run.

Álvarez (2016), using data for manufacturing and services in Chile, analyzes the effect of R&D and ICT on innovation and productivity. The results indicate that for firms in the services sector, the predicted ICT investment is the only relevant variable to explain the presence of any type of innovation and technological innovation (both proxied as dummies). R&D is not significant in both regressions. However, when all firms are analyzed, both variables (R&D and ICT) are significant to explain "Any Innovation" and "Technological Innovation." In the productivity equation, when the variables Any Innovation and Technological Innovation are introduced one at a time, they are positively correlated with productivity for both samples (all firms and firms in the services sector). However, when the predicted ICT investment is included together with the predicted innovation variable (any of the two), the coefficients of the innovation variables became nonsignificant both for all firms and for firms in the services sector. Again, this suggests problems of multicollinearity between the predicted innovation that already "contains" the predicted ICT investment and the predicted ICT investment. The variable R&D is not included in the productivity regressions. The impact of ICT investment on innovation and productivity seems to be larger for all firms. In our case, the point estimates for service sector firms in the productivity equation are larger than those for the manufacturing sector firms, which is somehow different to the findings for Chile.

Polder *et al.* (2009), using manufacturing and services data for the Netherlands, analyze the role of ICTs and R&D in innovation and productivity. They distinguish three types of innovation: process, product and organizational. They find that ICT investment is relevant for the three types of innovation in the case of the services sector and only for organizational innovation in the case of the manufacturing sector. R&D is only significant in the case of product innovation in the manufacturing sector. In the productivity equations, the predictions of the probability of different innovation combinations are included in the productivity equations. The sign of coefficients and significance vary for the different predicted probabilities. Unlike Polder *et al.* (2009), ICTs in our case are also very relevant to explain innovation in manufacturing.

We will conclude this section by analyzing if the results reported in the previous subsections support the three expectations presented in the article's introduction.

First, there is some support for the first expectation, at least in terms of the ICTs and IInict effect on P(Tech = 1 and Non-Tech = 0) and P(Tech = 1 and Non-Tech = 1) and productivity. If we look at Columns 2 and 6 of Table 6, we can see that ICT (IInict) seems to be more (less) important for technological innovation (i.e. for P(Tech = 1 and Non-Tech = 0) and P(Tech = 1 and Non-Tech = 1) in the services sector than in the manufacturing sector. However, if we look at Column 4 (i.e. the impact on the probability of introducing nontechnological innovations alone), the reverse is true. In terms of productivity the point estimates for the ICT variables are bigger for the services sector than for the manufacturing sector.

The second expectation was met when we consider nontechnological innovation alone. ICTs are more important than other types of investments for nontechnological innovations (alone). IInict has a negative impact on P(Tech = 0 and Non-Tech = 1), while ICT has a positive impact for both sectors.

Finally, there is some support for the final expectation. Nontechnological innovation alone or together with technological innovation has a positive effect on productivity in the service sectors (technological innovation is not significant), while it has a negative effect on productivity in the manufacturing sector. Technological innovation is the only one that has a positive effect product in the manufacturing sector.

6. Conclusions

The evidence about the impacts of ICT and other innovation activities on technological and nontechnological innovation and productivity in the services sector *vis-à-vis* the manufacturing sector, particularly for developing countries, is scarce. This article helps close this knowledge gap by estimating a CDM-type three-stage model for Uruguayan data.

The main conclusions of our article are:

1. ICTs seem to be more important for innovation and productivity in the services sector than in the manufacturing sector. The only exception is the role of ICTs in nontechnological innovations alone.
2. The investment in all other innovation activities is more important for the introduction of technological innovations in the manufacturing sector than in the services sector. The reverse is true for nontechnological innovations alone. This variable seems to be relatively not very relevant for the productivity in both sectors.
3. Nontechnological innovations are more important for productivity in the services sector than in the manufacturing sector. The reverse is true with technological innovations.

Some of the results found in this article are aligned with the received literature, while others are not. Similar to Hall *et al.* (2012), and different to Polder *et al.* (2009), our findings suggest that investment in ICT increases the probability of both technological and nontechnological innovations in manufacturing. In the same direction as Álvarez (2016) and Polder *et al.* (2009), we find that ICT investment seems to foster innovation in the services sector.

The three papers cited in the previous paragraph compare the impact of ICTs with those of R&D on innovation. Two of them find a less-relevant R&D role for innovation (Álvarez, 2016 and Polder *et al.*, 2009). Our article broadens the focus and looks at the contribution of all other innovation activities (where R&D is just one of them). Our conclusion is that (at least for the Uruguayan data), investment in other innovation activities is very relevant to explain innovation, and therefore, it suggests that future research should pay more attention to other innovation activities beyond R&D.

Judging from our results, to some extent, the distinction between the manufacturing and services sectors seems to be warranted, since indeed some heterogeneities were found across sectors. However, it is possible that the more important heterogeneities could be found with different cuts of the data, for example, by firm size, knowledge intensity, or high- and low-technological classification, etc. This is part of the future research agenda.

Our results provide interesting policy recommendations. Nowadays, available information on budgetary allocations and policy documents for developing countries shows that innovation policy and instruments are—in an imitation from more developed economies—predominantly directed toward intangibles, such as R&D investment. At the same time, areas in the services sector tend to be underscored in terms of their importance as productivity enablers of other sectors (such as manufacturing) and of the economy as a whole. The evidence presented here suggests that agencies promoting innovation should encourage ICT investments across the economy, particularly for firms in the services sector, and at the same time enhance comprehensive innovation strategies that induce a *make and buy* (Veugelers and Cassiman, 1999) strategy, which includes ICT investments. Similarly, these agencies should stress the importance of nontechnological innovation, particularly for the services sector. Without these improvements productivity suffers, even in manufacturing industries.

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Appendix

Table A1. Definition of variables

Variable	Source	Description
Technological innovation	IS	Dummy = 1 if firm introduced product or process innovation in the period of the survey
Non-technological Innovation	IS	Dummy = 1 if firm introduced organizational or marketing innovation in the period of the survey
Productivity	IS	log(sales per employee). End of year of survey. In local currency at constant prices.
ICTI		Log of investment in ICT innovation activities per employee. Year-end survey. In local currency at constant prices.
D (No ICTI)	IS	Dummy = 1 if ICTI = 0.
IInict	IS	Log of innovation investment in all other innovation activities (except ICT). Year-end survey. In local currency at constant prices.
L (=size)	IS	log number of employees. Year-end survey
D(Foreign_owned)	IS	Dummy = 1 if foreign capital greater than 10%. Year-end survey
D(Patent)	IS	Dummy = 1 if firm applied for patent in the survey period
D(Exporter)	IS	Dummy = 1 if firms exports. Year-end survey
D(Public support)	IS	Dummy = 1 if firm obtained financial support from government in the period of the survey
D(Cooperation_R&D)	IS	Dummy = 1 if firm was linked to some institution for design or R&D in the period of the survey
D(Market info)	IS	Dummy = 1 if importance of market sources (suppliers, clients, competitors, consulting firms, experts) was very important or important in the period of the survey
D(Scientific info)	IS	Dummy = 1 if importance of scientific sources (universities, public research center, technological institutions) was very important or important in the period of the survey
D(Public info)	IS	Dummy = 1 if importance of public sources (journals, patents, magazines, expositions, associations, databases, Internet) was very important or important in the period of the survey
H	IS	Log of share of skilled employment (professional and technicians over total employees). End of year
D(h = 0)	IS	Dummy = 1 when h = 0.
k	EAS	Log of total fixed assets over employees. Year-beginning survey.

Table A2. Average marginal effects on expected outcomes conditional on selection

Variables	Manufacturing		Services	
	(1) E(IInict|Iinict > 0)	(2) E(ICTI|ICTI > 0)	(3) E(IInict|Iinict > 0)	(4) E(ICTI|ICTI > 0)
D(Exporter)	0.136	−0.037	0.081	−0.086
	(0.127)	(0.147)	(0.167)	(0.137)
D(Foreign_owned)	−0.178	0.687***	0.0005	0.804***
	(0.178)	(0.190)	(0.228)	(0.267)
D(Patent)	0.009	−0.246	−0.462	−0.340
	(0.318)	(0.173)	(0.449)	(0.229)
D(PubSupport)	0.983***	0.351	−0.543	−0.690
	(0.147)	(0.294)	(0.506)	(0.540)
D(Coop_RD)	0.812***		0.118	
	(0.250)		(0.337)	
h	2.047***	2.291***	1.519***	1.199**
	(0.729)	(0.549)	(0.279)	(0.489)
D(h = 0)	0.511**	0.177	−0.469***	−0.260
	(0.233)	(0.339)	(0.160)	(0.217)
D(Market info)	0.116	0.369	0.172	−0.312
	(0.165)	(0.272)	(0.213)	(0.326)
D(Scientific info)	−0.122	−0.010	−0.018	−0.045
	(0.193)	(0.116)	(0.094)	(0.229)
D(Public info)	−0.0005	−0.001	0.134	0.049
	(0.138)	(0.213)	(0.130)	(0.144)

Standard errors in parentheses. Delta method.
***$P < 0.01$,
**$P < 0.05$,
*$P < 0.1$. All regressions include two-digit ISIC sector dummies.