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Innovation, public support and productivity in Colombia.

A cross-industry comparison

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Abstract

We investigate the association between perceived barriers to innovation and the allocation of public support for innovation in manufacturing and service industries in Colombia, as well as the potential heterogeneity of returns to innovation across the firm-level productivity distribution. We extend the CDM recursive system by including an equation for the allocation of direct support and using quantile regression methods to estimate the productivity equation. We find some differences across manufacturing and service industries. Financing constraints are correlated with obtaining public support in manufacturing and in some services, but in knowledge intensive services (KIS) barriers associated with regulations are more significant. The introduction of innovations increases mostly the productivity of firms below the median of the productivity distribution, especially in services. Increasing human capital would boost productivity of firms in all industries, providing support to the hypothesis that human capital is indeed a bottleneck for productivity growth across the board in Colombia. We conclude that addressing factors that hinder innovation by low productivity firms in all service industries could significantly contribute to increasing productivity and reduce its dispersion.

Keywords: CDM model, innovation, productivity, public support, quantile regression, Latin America

JEL Classification: O31, O32, O33, O40, L8, C30

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1. Introduction

In this paper we contribute new evidence on the relationship between public support, innovation and productivity at the firm level in Colombia by investigating several underexplored issues. First we identify and compare the profile of firms that have access to public support for innovation in manufacturing and service industries separately; second, we examine whether the association between the introduction of innovations and productivity varies across the productivity distribution; third, we distinguish between technological and non-technological innovation, since the latter may be especially relevant in the service industries relative to manufacturing.

Colombia has experienced a steady growth of GDP per capita during the last decade. According to a recent report by the OECD, the commodity boom and macroeconomic reforms have been driving this performance; but productivity remains low (OECD 2015). Developing an environment that increases the opportunities for and returns to innovation in all sectors can make a difference and complement other policies designed to stimulate sustained productivity growth, such as improving the regulatory framework, the financial system and the quality of education (Goñi and Maloney, 2014; Nguyen and Jaramillo, 2014).

Comparative empirical research carried out for several Latin American and Caribbean countries (LAC) shows that both technological and non-technological innovation increase labor productivity in manufacturing industries (Crespi and Zuniga 2012, Crespi et al. 2016). In 2013, however, manufacturing accounted for about 11% of GDP in Colombia, while the share of services was close to 60% and on average contributed 2.8 percentage points to GDP growth during the period 2005-2013 (OECD 2015). The evolution of productivity in the service industries will therefore have a significant impact on aggregate productivity and growth. The ability to innovate in these industries can be expected to play a major role in this evolution, not only because of their weight but also because the role that some, like consulting services, play on the productivity of many other firms, especially on small and medium ones, through improving managerial capital (Bruhn et al. 2013).

Business investment in R&D in Colombia is low: it accounts for about 30% of all R&D investment, below the average rate of 40% in Latin America, which is in turn well below the 65-75% business share in advanced countries (OECD 2014). Yet, the degree of business sector involvement in R&D and more generally in innovation is important not only for developed countries but also for countries that are or intend to be on a catching up path. Extant evidence shows that countries and firms can benefit from others' knowledge and innovations provided that they develop absorptive (technology transfer) capabilities. Investing in innovation activities, especially in R&D, enables this process (Griffith et al. 2004; Li 2011).

Colombia has implemented specific policies to promote innovation in the business sector: in particular, tax deductions for R&D and technological development projects, and direct support through subsidies and loans, are available to firms. Little is known, however, about who benefits from this support, how its allocation correlates with actual or perceived barriers to innovation and to innovation effort, and whether the returns to innovation differ significantly across the firms' productivity distribution.

To investigate these issues we use two firm-level datasets gathered by the Colombian National Statistics Department (DANE): the Survey of Innovation and Technological Development in Services, EDITS-III (2010-2011) and the Survey of Innovation and Technological Development in Manufacturing, EDIT (2009-2010).[1] Because these are basically cross sectional data, we mainly aim at uncovering regularities and correlations that may be informative from a policy perspective, but cannot claim to establish causal relations.

The following results stand out. Regarding access to public support, we find some differences across sectors: in manufacturing and traditional service industries the probability to obtain direct public support is higher for firms that face high financing constraints. In knowledge intensive services (KIS), in contrast, this type of constraint is not found to be significantly associated with public support; instead, firms reporting that complying with regulations is an important barrier for innovating are more likely to obtain it. If regulations respond to efficiency criteria, this would suggest that public funds complement other policies. But if regulations create inefficiencies instead of

[1] DANE is the acronym for Departamento Administrativo Nacional de Estadística. See the website: www.dane.gov.co. EDIT is the acronym for Encuesta de Desarrollo e Innovación Tecnológica.

addressing them, then public support may just be a means to partially offset their negative effects. We also find that in all industries firms that invest in R&D are more likely to obtain support, implying that knowledge generation, rather than pure imitation, is encouraged.

Regarding returns to innovation, we find that in manufacturing industries introducing innovations (product, process or non-technological) increases productivity at all levels of the productivity distribution. In contrast, in service industries including KIS, the introduction of all types of innovations increases productivity of firms below the median of the productivity distribution more than the productivity of those above. This suggests that less productive firms would benefit relatively more from introducing innovations, and that reducing barriers to innovation in the least productive firms would narrow down the productivity dispersion as well as increase the mean significantly.

The outline of the paper is the following: in section 2 we address some conceptual issues, discuss closely related previous work and explain how we extend it; section 3 contains a description of the data we use from the Colombian firm-level innovation surveys; in section 4 we lay out the empirical framework and the hypotheses that will be tested; section 5 discusses results, and in section 6 we summarize our findings and draw implications for policy and further research.

2. Previous work, conceptual issues and open questions

The accessibility to data from innovation surveys conducted by national statistical offices in an increasing number of countries has enabled the expansion of empirical research on the determinants of investment in innovation and on the private and social returns to these investments. The development by Crepon, Duguet and Mairesse (1998) of an empirical framework to investigate simultaneously, at the firm level, the chain of links between the decisions to invest in innovation, the production of technological innovations, and their effect on productivity has contributed to a great extent to this progress. This empirical framework -known as the CDM model- consists basically of a system of four recursive equations where the first two model the decision to invest in R&D and investment effort, conditional on deciding to invest at all; the third models innovation output as a function of R&D investment, and finally innovation output enters the productivity equation.[2]

Cross-country comparative studies based on firm level data for manufacturing industries in developed countries have uncovered some regularities that hold across their diverse institutional and economic environments. For example, in European countries, the probability of engaging in R&D is generally associated with exposure to international competition, firm size and access to public funding; R&D investment intensity is highly correlated with introducing product and process innovations, and product innovation in turn is positively correlated with labor productivity (Griffith et al. 2006; Hall et al. 2010).[3] Similar patterns are observed in manufacturing industries in emerging countries (Jefferson et al. 2006).

To what extent do these regularities hold in the service industries, which account for a large share of GDP in developed countries as well as in many developing countries? Services include a large and very heterogeneous set of activities that differ from manufacturing in several respects. First, many produce mostly intangible outputs, which often present more measurement difficulties than tangibles. In addition, intangibility of many services means that they may be affected, to a greater extent than manufacturing industries, by issues derived from asymmetric information regarding service quality and properties. Some services consist precisely on the provision of information -consulting services, health, education, research, financial services-, and information goods have some distinctive traits. One of them is that their quality and value to the user or consumer may be uncertain until it is consumed; this may provide more room for problems such as adverse selection and moral hazard, which are consequences of the asymmetric information between the two parts of a transaction. It is well known that asymmetric information can generate market failures in financial, insurance and health services. These market failures are likely to affect costs and rewards of innovating. For instance, they can raise the cost of capital for corporations, reducing investment in general (Choi and Yan 2013).

[2] For a recent extension that introduces dynamics into the model see Raymond et al. (2015).
[3] Aw, Roberts and Xu (2011), using plant-level data for the Taiwanese electronics industry, provide further evidence on the dynamic links between decisions to invest in R&D, exporting and productivity.

A second difference between manufacturing and service industries is that competitive pressure varies across activities: only some services are internationally traded, in contrast to manufacturing goods. Openness to trade is usually positively correlated with innovation, both in manufacturing and services (Zahler et al., 2014). Third, and related to the previous point, government regulations such as restrictions to FDI, barriers to entry and conduct regulations affect many services (telecommunications, professional and financial services, utilities, health services, education). These may influence firms' incentives to innovate or to adopt innovations, and ultimately affect productivity and its growth. Gruber and Koutroumpis (2013), use data on the adoption of broadband services in a panel of 167 countries and assess the effects of different regulatory frameworks on adoption of innovations; Andrews and Cingano (2014) provide broad evidence on the relation between policy frictions and productivity. Marel et al. (2016) are the first to assess the effect of services regulation on productivity using a large data set at the firm level in a multiple-country setting -EU members-. They use services policy indicators across countries and several TFP measures at the micro-level to track down this relationship. Furthermore, they separate an overall index of regulations into restrictions that refer only to entry barriers and restrictions that concern the operations of the firm -conduct regulations-. Their results suggest that reducing these restrictions would increase the productivity performance of firms operating in both services and manufacturing industries, and that lowering regulations on the operations of the firms would have an impact on firm-level TFP in all countries. Finally, they find that institutionally weak countries - meaning weak or unqualified regulatory bodies, and low level of trust- are more likely to suffer significantly more from restrictive regulations.

Many innovations in most manufacturing industries are based on the ability to generate new knowledge by engaging in costly activities, and their outcome -knowledge- may be subject to spillovers that reduce private returns and therefore the incentives to carry them out. In services, however, innovation sources may be more diverse: some may be based on ideas that involve the adoption of ICTs, or on organizational or marketing changes that are less likely to involve significant idea development costs relative to knowledge spillovers; the returns to innovation may therefore be less affected by this potential source of market failures. On the other hand, knowledge intensive business services might be different in this regard. We next discuss this along some measurement issues.

2.1. Measurement of productivity and innovation in manufacturing and service activities.

The measurement of output, productivity and innovation in services has been a challenge for statistical agencies responsible for quantifying and characterizing economic activities. In particular, the measurement of average capital and labor productivity and of multifactor productivity in market and non-market services, has been addressed by economic researchers for some time. In his introduction to a volume collecting the contributions to a conference organized in 1990, Griliches (1992) wrote: "the possibility that difficulties in measuring output and prices in services may have resulted in a mismeasurement of productivity growth in these sectors, a mismeasurement that accounts for some or even much of the observed contrast with the productivity experience of commodities".[4] The volume edited by Berndt and Hulten (2007) provides an account of contributions to measurement since Griliches. In one of the chapters, Bosworth and Tripplet describe some of the advances and use currently available data and methods to compute productivity. They find that, in the USA in particular, labor productivity growth in the 1995-2001 period was higher in the service industries than in goods industries; within-industry heterogeneity though was also high, both within manufacturing and within service industries. Evidence shows that dealing with measurement issues has implications for establishing economic facts and analysis: widespread beliefs that services are characterized by low productivity or low capital intensity are not confirmed when better data are collected. Data improvements are thus key for characterizing similarities and differences both within and across economic activities and to testing hypothesis about productivity and the role of innovation in these activities.

Some authors emphasize that misconceptions about services regarding their productivity and their potential for innovation still seem to persist. Gallouj and Djellal (2010) refer to some popular myths, according to which service activities exhibit low-capital intensity and low productivity growth, and play a subordinate role in innovation: services would be technology adopters rather than generators of innovations. To challenge these views, Gallouj and Djellal provide examples of non-technological innovations that have taken place in services, such as new insurance contracts, new financial instruments, or new

[4] Griliches collaborated with government economists and statisticians in statistical agencies to improve measurement of output and prices of all economic activities, and inspired other scholars to do so.

formats for restaurants and retail outlets, making the point that in services innovations are not necessarily linked to technology in strict sense, but they are innovations of a non-technological nature. Unless this type of innovations is taken into account by statistical bodies, it will go unnoticed. They also observe that at least for some services there is room for innovation through improvisation, which adds to the invisibility of innovation activities.

Djellal and Gallouj (2010, ch. 27) note that OECD manuals providing guidelines for the measurement of innovation and knowledge activities have evolved in order to reflect the changes that have taken place over time with respect to what and how innovation is performed in all economic sectors, including services.[5] Thus, while measurement issues certainly call for further work, the quality and scope of indicators of innovation inputs and outputs in all industries, including services, have been improving over time, allowing for a better description of facts and analysis. Recent national innovation surveys show that in most countries a majority of firms introduces technological and non-technological innovations simultaneously, and a smaller share introduce only marketing or organizational innovations, or only product or process innovations (see OECD STI Scoreboard 2015, pp. 162-163). We also observe that in service industries a higher percentage of firms introduce only non-technological innovations than in manufacturing industries, but still the percentage introducing all types of innovations simultaneously is generally higher in both industries.

What about cross industry differences in how innovations are developed? Innovations are the outcome of implementing new ideas connected with the production and delivery of goods and services. In some but not all cases finding and implementing new ideas may require a significant effort: "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge". When this work is systematic, creative, uncertain, reproducible and novel, it is called R&D (Frascati

[5] The Frascati Manual, first published in 1962, has been revised several times to keep up with new measurement needs as the scope of knowledge and innovation has been expanding; in 2105 the seventh revision has been published. The OECD's Oslo Manual, first published in 1992, was last revised in 2005. The main novelty of the last revision was precisely the specific attention paid to capturing non-technological innovation -marketing and organizational-, linkages between different innovation types and innovation in services. Furthermore, the concept of innovation activities includes not only R&D investment, but also development and support activities, such as market preparation, acquisition of external knowledge or capital goods, and training.

Manual definition). R&D is thus one input for innovation, but possibly not necessary nor sufficient to obtain some types of innovations: certain marketing and organizational innovations can be invented and implemented without investing in R&D. To the extent that these types of innovation are more frequent in service than in manufacturing industries, we would expect R&D activities to be less used in the former, as observed so far. This may change in the near future, however, as recent developments in the scientific fields of psychology, neurosciences and behavioral economics suggest that R&D activities are likely to play an increasing role in generating these type of innovations across all industries, and maybe especially in services.

Innovative activities are very heterogeneous across service industries with respect to the costs and methods of innovating. Innovation, in many instances and in all industries, does not necessarily rely on systematic activities to obtain scientific and technical knowledge, but on informal human ingenuity, interactions with suppliers and customers, new combinations of other innovations. Some examples illustrate the diversity of innovation in services, as well as how its sources may change over time: Google, a firm specialized in Internet-related services and products, has a wide portfolio of research projects, investing about 13% of its revenues on R&D and covering a wide range of fields. In the food services, culinary chefs are involved in research with food scientists to explore new ways of cooking (think of instance molecular gastronomy, for instance). Administrative and support services are likely to rely on innovation through suppliers' R&D: think for instance of robots for office and building cleaning. Organizational and marketing innovations may or may not rely on R&D. Some illustrative examples come to mind. Bicycle sharing systems in large cities (*bicing*) are land transportation innovations that do not necessarily require R&D.[6] In contrast, innovation in education or organizational change in private -or public- organizations may benefit from applied research and experiments linked to behavioral and psychological sciences (Beshears and Gino 2014).

[6] "Bicing" consists of a network of stations to lend and return bicycles in large cities. Many stations are located next to public transport stops; each bike serves several users per day. This system is often implemented through public-private partnerships, and IT has enabled its recent success. Previous attempts to introduce this service failed mostly because of the difficulties to control for theft and vandalism. Some examples where this innovation has been successfully implemented are Barcelona, Melbourne, Paris, Stockholm and Wuhan among others.

Recent work by Galindo Rueda and Verger (2016) provides a classification of all economic activities, including a wide range of services, according to their R&D intensity, following the latest revision of the OECD Frascati Manual and the ISIC classification of activities, Revision 4. Industries are classified into five groups: high, medium-high, medium, medium-low, and low R&D intensity. They find that two service activities, namely scientific research and development and software publishing are classified as high R&D intensity industries, while IT and other information services are ranked as medium-high R&D intensity. No services would be classified as medium R&D intensity activities; while several manufacturing industries would be included in this category: rubber and plastic products, building of ships, basic metals, among others. Professional and technical services (except scientific R&D), telecommunications services and publishing of books and periodicals are classified as medium-low R&D intensity activities. The class of low R&D intensity industries includes remaining services -financial and insurance, utilities, audiovisual and broadcasting, wholesale and retail trade, arts, transportation and storage, real estate and accommodation and food service activities. It thus appears that service activities are quite polarized in terms of R&D intensity, unlike manufacturing activities, where R&D intensity varies gradually. This does not mean, as the examples discussed above illustrate, that low R&D intensity industries cannot be innovative. It means that the cost of innovating is unlikely to be high relative to benefits, or that technical risk is likely to be low. Imitation is less likely to deter a firm from innovating, as lead advantage can give the firm a high enough payoff.

2.2 Evidence

How do differences described above between manufacturing and service industries affect incentives to innovate in each industry? Does the impact that innovations have on productivity differ as well? Studies for developed countries find that similarities are substantial, especially for some types of services. Work by Loof and Heshmati (2006) for Sweden, Arvanitis (2008) for Switzerland and Musolesi and Huiban (2010) for France shows that investment in internal or external R&D and introduction of innovations in services are significantly correlated, and that innovations affect productivity, as in manufacturing.[7] In addition, Mussolesi and Huiban find that firms in KIS that receive public support are more likely to introduce technological innovations, although not other types of innovation.[8] Studies by Segarra (2010) with CIS 2002-2004 for Catalan firms, and Peters et al. (2014) with CIS 2006-2008 for the United Kingdom, Germany and Ireland, corroborate the positive relationship between innovation and productivity in services.[9]

Do determinants and consequences of innovation in manufacturing and services in Latin America, and in Colombia in particular, follow similar patterns as in developed countries? Empirical research has provided evidence mostly for manufacturing industries.[10] Raffo et al. (2008) and Crespi and Zuniga (2012) have performed comparative cross-country studies for manufacturing industries in LAC using the CDM framework.[11] Although their respective empirical specifications differ, they all find that the probability of investing in innovation activities (Raffo et al. 2008) or in R&D (Crespi and Zuniga 2012) increases with firm size; that the probability of introducing product or process innovations depends on the magnitude of this investment, and that productivity (usually proxied by sales per employee) is higher for firms that introduce innovations in almost all LACs investigated. Crespi and Zuniga (2012) in particular conclude that promoting innovation can indeed be an effective way to increase productivity in LACs, and that the main policy concern should be removing the obstacles that deter manufacturing firms from investing in innovation.

Many governments in LACs have implemented programs to foster innovation in the private sector. Like in OECD countries, some provide direct support through matching

[7] Musolesi and Huiban (2010) focus on KIS services. They find that R&D activities and the acquisition of equipment, licenses or software are a significant determinant of the decision to produce technological innovations, but not non-technological ones. All innovations have a strong and positive effect on productivity, measured by added value of the employee.

[8] The relationship between firm size, foreign ownership and investment in innovation activities in services and type of innovation -process vs. product; technological vs. non-technological- varies across these countries, possibly reflecting institutional differences.

[9] As to the incentives to invest in innovation, Segarra (2010) and Peters et al. (2014) find that firm size and participation in international markets are positively correlated to the probability of investing in innovation, much like manufacturing firms.

[10] Alvarez et al. (2015) use the CDM framework to compare the links between innovation and productivity in manufacturing and service firms in Chile, finding many similarities.

[11] Raffo et al. (2008) estimate the same CDM model for France, Spain, Switzerland, Argentina, Brazil and Mexico. Crespi and Zuniga (2012) focus on six LACs, including Colombia. For an empirical analysis of individual LAC countries, see for example Benavente (2006) for Chile; Chudnovsky et al. (2006) for Argentina; Tello (2015) for Peru, Aboal and Garda (2015) for Uruguay, and Rodriguez Moreno and Rochina (2015) for Ecuador.

grants, non-refundable grants and credit lines to firms that have innovation projects. Alvarez et al. (2015) for Chile, and Gallego et al. (2015) for Colombia, use the CDM framework to compare innovation effort and outcomes in manufacturing and service industries taking into account public support. Gallego et al. assume that public funding is not related to the discrete decision to invest in innovative activities, but only to innovation intensity.[12] They find public support to be the most important variable associated with innovation intensity in KIS but not in traditional services, and that innovation effort in turn is correlated with labor productivity in all industries. These findings suggest that access to finance by potentially innovative firms can be a significant barrier for increasing the mass of innovating firms in some industries in Colombia and other LAC, but these studies do not investigate this specific question further.[13]

Recently Crespi et al. (2015) evaluate the impact of some programs from the Colombian Innovation Agency (COLCIENCIAS) on the productivity of manufacturing industries over the period 1998-2007.[14] Their evidence supports the conclusion that these programs have a positive effect on the introduction of new products and on labor productivity in the long term; they do not investigate, however, whether public support is correlated with innovation barriers that firms perceive to be important. From a policy perspective it is essential to know whether public support addresses in practice common sources of underinvestment in innovation, such as access to financing or other innovation specific barriers (Busom et al. 2014). Even if support programs have positive effects on some measures of performance, this does not prove that they correct financing or other market failures that often affect innovation. Evidence that Colombian manufacturing firms face constraints in accessing to credit, although not specifically for innovation activities, is provided by Eslava et al. (2014), who show that public untargeted lending programs ease these constraints -especially long term lending-, allowing firms that benefit from them to grow and invest.[15] These observations lead us

[12] Gallego et al. (2015) use EDIT 2007-8 for manufacturing, and EDIT 2008-9 for services. Their sample of service firms has a smaller number of observations (562 firms) than ours.

[13] In addition they assume that receiving public support is uncorrelated with unobserved variables in the innovation investment decisions.

[14] Research to evaluate the effectiveness of this type of programs has been expanding. Hall and Maffioli (2008) provide a review of existing evidence for some LAC.

[15] Eslava et al. (2014) use a large sample of loan beneficiaries and firm-level data from the Annual Manufacturing Survey over the period 2004-2009. They use propensity score (PS) estimates to match beneficiaries and non-beneficiaries and obtain impact estimates; the specification for the PS is not shown,

to expand the CDM model with an additional equation in order to test whether public funds reach financially or otherwise constrained firms willing to innovate, and whether observed support allocation patterns differ across industries.

Another issue that has not been investigated in depth is whether private returns to introduction of innovations vary significantly across firms. Firm level productivity is known to be highly heterogeneous within industries in a given country, reflecting differences in managerial talent, labor quality, R&D or export status as well as factors external to the firm such as poor regulation (Syverson 2011). Most research on the relationship between these variables and productivity measures is based on estimates at the conditional mean of the productivity distribution. These estimates, however, may not reflect accurately the link along the whole productivity distribution. Quantile regression methods may be more appropriate when the distribution of the outcome departs from normality. To illustrate, Yasar et al. (2006) and Powell and Wagner (2014) show that the relationship between export status and productivity varies across manufacturing firms' productivity levels in Turkey and Germany, respectively. It turns out that in Turkey the productivity effects of exports are larger at the upper tail of the distribution, while in Germany evidence suggests the opposite result.

Most empirical studies on the returns to innovation or to R&D are based too on estimates of the innovation (or R&D) premium at the conditional mean of the productivity distribution. Only a few authors have explored whether returns to innovation vary across the distribution using quantile regression methods. Some examples are Coad and Rao (2008), who find that innovation is important for some fast-growth firms in the US; Segarra and Teruel (2011), in contrast, find that internal R&D investment in Catalonia has a highest impact on the productivity of firms in the lowest quantile rather than on those in the highest quantile. Similarly, Damijan et al. (2012) also find that manufacturing firms with below average productivity benefit more from innovation than other firms in Slovenia.[16] Finally, Bartelsman et al. (2015) find that returns to product innovation are higher for more productive firms in most industries - manufacturing and services- in Germany and the Netherlands, while returns to process

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and we cannot compare it with our estimates. Daude and Pascal (2015) provide evidence that the efficiency of the Colombian banking system could be improved.

[16] Segarra and Teruel (2011) use a sample of Catalan manufacturing and KIS firms; Damijan et al (2012) use data from Slovenian firms; in both cases the data sources are the respective Community Innovation Surveys (CIS).

innovations seem to be negative in service industries. This result would suggest that public support to innovation should not be assigned to process innovations in service industries unless significantly positive knowledge spillovers are involved.

It is likely that the link between productivity and innovation activities in Colombian firms exhibits a high degree of heterogeneity as well, especially in service industries. According to Busso et al. (2013) total factor productivity at the firm level shows a high dispersion in several LAC relative to the US, particularly in Colombia. This would have implications for innovation policy. If private returns to innovation -as measured by their contribution to labor productivity- are higher for more productive firms, then direct public support for innovation should focus on the subset of productive firms that may face innovation barriers. If returns to innovation are the same on average for all firms at any productivity level, then there would be no need for a targeted support policy. But if instead the innovation premium is higher for firms in the lower tail of the productivity distribution, public effort should address the factors that deter innovation in these low productivity firms.

3. Data and variables

The Colombian National Statistics Department (DANE) conducts two innovation surveys, one for manufacturing firms (EDIT), and another for service firms (EDITS), following the OECD Oslo and Bogota Manual guidelines.[17] For manufacturing the sample includes establishments with 10 or more employees or with an annual production greater than USD $68,700 according to the directory of firms from the Annual Manufacturing Survey (ASM). For the service sector survey (EDITS), sample inclusion parameters vary across activities according to the one digit level ISIC classification: while all firms in financial intermediation are sampled, in other service activities only those with more than 20 employees -or more than 50 in some cases- or a given level of sales are included (see Table A1 in the Appendix). The sample does not intend to represent the whole universe of firms in service industries.

We use the 2010-2011 wave for the services sector (EDITS 2010-2011), and the 2009-2010 wave for manufacturing (EDIT 2009-2010). Our working sample consists of 905

[17] The Colombian statistical office (DANE) pays special attention to the specific features of service activities relative to manufacturing and takes into account the reflections made by Gallouj and Djellal (2010) and others in this respect when designing the innovation survey. See DANE (2014).

manufacturing firms, 954 firms in knowledge intensive business services (KIS), and 1419 firms in remaining service activities, which we will refer to as traditional.[18] Table 1 shows the composition of the sample by industry and firm size.

[Insert Table 1 about here]

Innovation surveys collect information on firm features (size, human capital, exporting status), on their innovation activities and output, including the firms' perceptions concerning the importance of some barriers to innovation, and whether the firm has benefited from public funds to innovate. Some of the survey questions refer to the two year period, and others to the survey year and/or the year before. Innovation activities include internal and external R&D, investment in physical capital or ICTs to produce new goods or services, marketing and design expenditures for innovations, technology transfer payments, and specialized training.

In our sample about 28% of firms in KIS, 30% in traditional services and 31% in manufacturing report having invested in some innovation activity within the survey period. Table 2 provides a description of the main innovation related activities. Table A2 in the Appendix provides the definition of each variable. In service industries including KIS the percentage of firms that engage in R&D is about half of those that invest in innovation activities, while in manufacturing the percentage is higher, especially across firms with more than 50 employees. This is consistent with the usually higher importance of introducing innovations by adopting ICTs in services.

Process and organizational innovations are more frequent, on average, than product or marketing innovations, but they are all highly correlated. The pairwise tetrachoric correlation across innovation types is very high: 0.85 between product and process innovations in KIS, 0.78 in traditional services and 0.80 in manufacturing; the correlation between process and organizational innovations shows similar values. This suggests that firms that introduce one type of innovation are very likely to introduce another as well, possibly because of complementarities among them (Ballot et al. 2015). As a matter of fact, this pattern is found in other countries as well. According to the

[18] Traditional services include wholesale and retail trade, hotels and restaurants, health and social services, other social and personal services, as well as utilities, while KIS includes business services; financial intermediation and transport, storage and communications. See Table A1 for more details on sample composition.

OECD STI Scoreboard 2015, in Sweden about 27% of innovative service firms introduce only one type of innovation; in Turkey the percentage is 27% as well, and in Spain it is 20%. The Scoreboard also provides information for Colombia: for years 2012-13, only 26 percent of firms introduced only one type of innovation. Furthermore, the picture is not very different in manufacturing industries: the percentage of firms introducing only one type of innovation was 29%, 26% and 21% respectively for the first three countries. In Colombia, with 18%, it was even lower.

In our sample we observe some differences across types of innovation: introduction of process innovations is somewhat more extensive than other types of innovations in all industries, especially in KIS, while product innovations are more common in large manufacturing firms (see Table 2). Organizational innovations are slightly more widespread in KIS, but we do not observe significant differences across industries in the introduction of marketing innovations. As observed elsewhere, the percentage of firms that introduce any innovation increases with firm size in all industries.

The distribution of the log of sales per employee, which we will use as a proxy for labor productivity, exhibits some differences across industries and firm size. Dispersion is larger in service industries than in manufacturing, pointing to a greater heterogeneity among the former. In our sample, service firms at the 90th percentile of productivity are about 50 times -four times in the log scale- more productive than firms at the 10th percentile, both in KIS and in traditional services. In manufacturing the ratio is about 22 to 1. In addition, the distribution of the log of labor productivity is skewed to the right, especially in the case of traditional services. Extreme values are frequently observed in all industries, with a value for kurtosis of about 5, exceeding in two units that of the standard normal distribution. These differences are consistent with findings by Busso et al. (2013), who explore whether distortions in input and output markets in LAC contribute to explaining these differences in productivity. They find that resource misallocation is higher in services than in manufacturing, for countries where data for service industries are available. Variation in technologies and processes, in the distribution of human capital and management quality might contribute as well to explain these differences.[19] Finally, we observe in our sample that in service industries,

[19] Lemos and Scur (2015) provide a description of the distribution of management practices at firm-level in Colombia and other countries. They find that the average score of management practices in Colombia

both traditional and KIS, average productivity falls with size, in contrast to manufacturing, where productivity is higher in larger firms.

[Insert Table 2 about here]

A range of public programs provide support for business innovation in Colombia. Some supply grants that co-finance R&D and innovation projects at a rate below the full cost of a project (FOMIPYME, SENA, COLCIENCIAS).[20] According to the Colombian statistical office, DANE, about 60% of all public funds were provided through co-financing in 2010 (75% in 2011) in the case of services. Other programs (Bancoldex, and Bancoldex-Colciencias) provide loans (credit lines) to finance the whole cost of R&D and innovation projects. These refundable loans represent a very small share of public funds allocated to services (5% in 2011). In manufacturing, in contrast, most support (65% in 2009, and 42% in 2010) is provided through loans, while the share of co-financing is 15% and 20% each of these years. Finally departmental and local funds for science and technology projects are available as well (39% of total public funds in 2010 in the case of services, and a similar share for manufacturing).[21] In our sample, on average 4% of firms in the services industries and 8% those in manufacturing report having benefited from direct support during the survey period, although figures are smaller for small firms and increase with size.[22] Grazzi and Pietrobelli (2016) report similar percentages for Latin-American firms. We do not have disaggregate information by program; we only know whether a firm received any type of public support for innovation projects.

Table 3 describes some other relevant features of firms in the sample that may correlate with their ability to obtain public support and to innovate. First, a high percentage of firms report that financing constraints are a very important barrier for their innovation plans, especially for firms with less than 50 employees, and for a higher percentage of

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is below the expected value given its development level, and that the distribution of scores shows a long and thick tail of underperforming firms.

[20] *FOMIPYME* is the acronym for the program Linea de innovacion, desarrollo y transferencia tecnologica; and *SENA* for the Programa Innovacion y Desarrollo Tecnologico-Ley 344/96. COLCIENCIAS has a cooperation program, *Universidad CIA-CDT-Empresa*, and a risk sharing program, *Riesgo tecnológico compartido Empresa*.

[21] See DANE (2016).

[22] Colombia also provides some tax incentives: tax deductions from the corporate tax to firms that invest in R&D and income tax exemptions for software developers and others. We did not have access to information collected in EDIT on the use of tax incentives by firms in our sample. According to Mercer-Blackman (2008), however, very few firms use these incentives.

firms in manufacturing than in service industries. Foreign ownership is more prevalent as firm size increases, both in manufacturing and services. Exporting, an activity also correlated with firm size, is more common among manufacturing than among service firms, as expected. Market sources of information -from customers or from suppliers- are of much higher importance to firms than institutional sources -universities or government centers-. Finally, it is interesting to note the differences in the distribution of human capital across firm size and industry in the sample: in service industries we find a higher proportion of firms that have a high level of human capital than in manufacturing, across all firm size intervals.[23]

[Insert Table 3 about here]

4. Empirical modeling

4.1. An extended CDM framework

We introduce several novelties to the recursive, static CDM framework. First, we add a first stage that accounts for access to public funding for innovation activities. Obtaining public support is not the outcome of a random process, but rather the consequence of a firm's decision to apply for it and the public agency's to award it. It is thus likely to be correlated with unobservables in other innovation decisions, leading to potentially important endogeneity bias in subsequent equations. The discrete decision to invest in innovative activities and the intensity of innovation effort follow, where the estimated probability of obtaining public support is included in both equations as independent variable. Predicted innovation effort becomes an input into the likelihood of introducing several types of innovations. Finally we estimate labor productivity as a function of each (predicted) type of innovation separately, allowing for a potentially different correlation between innovation type and productivity across the distribution of productivity. Our system consists of five equations that we explain next, while we discuss our hypotheses on regressors as well as the potential endogeneity issues that arise in section 4.2.

The first equation describes access to public support for business innovation. $S_{i,}$ is observed as a binary variable, indicating whether a firm has received public resources

[23] This possibly reflects the different criteria used for sampling firms for the manufacturing and service surveys by DANE.

from sources explained in section 3 to carry out scientific, technological and innovative activities:

$$S_i = \begin{cases} 1 & if \quad S_i^* = \sum x_{0i}\beta_0 + \varepsilon_{0i} > c \\ 0 & if \quad S_i^* = \sum x_{0i}\beta_0 + \varepsilon_{0i} \leq c \end{cases} \quad [1]$$

We will estimate the probability of having obtained public support, $Pr[S_i = 1] = Pr[(\sum x_{0i}\beta_0 + \varepsilon_{0i}) > c]$ through a probit model using the whole sample of firms, as all of them may be potentially eligible for support. Note that we do not observe whether the firm has applied for it and has been rejected. The observed variable thus indicates success at applying and obtaining, reflecting both incentives of firms to apply and the public agency preferences. This equation should be interpreted as a reduced form.

Investment in innovation activities is split as usual in two decisions: whether to invest or not (g_i), and the magnitude of investment (r_i) in innovation activities, where the latter is observed only if the firm has decided to invest a positive amount.[24] These decisions may be correlated with receiving public support, S_i, as well as with additional variables x_1 and x_2 respectively:

$$g_i = \begin{cases} 1 & if \quad g_{0,i}^* = fSi + \sum x_{1i}\beta_1 + \varepsilon_{1i} > \tau \\ 0 & if \quad g_{0,i}^* = fSi + \sum x_{1i}\beta_1 + \varepsilon_{1i} \leq \tau \end{cases} \quad [2]$$

$$r_i = \begin{cases} r_i^* = mSi + \sum x_{2i}\beta_2 + \varepsilon_{2i} & if \quad g_i = 1 \\ \quad = 0 & if \quad g_i = 0 \end{cases} \quad [3]$$

Both equations are jointly estimated through a generalized Tobit model. The error terms are assumed to have a bivariate normal distribution. The introduction of innovations is observed as a binary variable which is a function of the predicted latent innovation effort and a set of other variables x_3:

$$I_i = \begin{cases} 1 & if \quad I_i^* = \alpha_I r_i^* + \sum x_{3i}\beta_3 + \varepsilon_{3i} > 0 \\ 0 & if \quad I_i^* = \alpha_I r_i^* + \sum x_{3i}\beta_3 + \varepsilon_{3i} \leq 0 \end{cases} \quad [4]$$

Equation [4] will apply to four possible types of innovation: product, process, marketing and organizational. Each is estimated through a separate probit model, providing four estimated probabilities. These four equations are like a seemingly unrelated system:

[24] These two dependent variables refer to total investment in innovation activities, including R&D.

they have the same independent variables, and feedback effects across dependent variables are assumed away. In this sense they are reduced forms. To explicitly study the extent of pair-wise complementarity between all four types of innovation requires correcting for time-invariant individual effects so as not to attribute the complementarity to individual time invariant characteristics (Mohnen and Hall 2013). Our data do not allow us to control for unobservables, so we do not pursue this issue here.

Finally, labor productivity, y_i, measured as the logarithm of sales per employee, is assumed to depend on the introduction of innovations and a set of other variables x_4:

$$y_i = \alpha_0 + \alpha_I I_i + \beta_4 x_{4i} + \varepsilon_{4i} \quad [5]$$

This equation is estimated replacing the innovation indicator I, by the estimated probability in [4], one at a time, and using both 2SLS and quantile regression methods.[25] Quantile regression allows the impact of regressors to vary along the distribution of labor productivity, which may be of importance in very heterogeneous industries such as services. Given $q \epsilon (0,1)$ and labor productivity (y_i), the qth quantile is

$$Q(q) = inf\{y_i: F(y_i) \geq q\} \quad [6]$$

where F is the distribution function of y_i. Assuming that the quantile q of the conditional distribution of productivity (sales per worker, y_i) is linear in x_i, the conditional quantile regression model is defined by equation [7]:

$$Q_q(yi|Xi) = Q(y)_{i,q} = \beta_{1q} Pr[\alpha_I r_i^* + \beta_3 x_{3i} + \varepsilon_{3i}] + \beta_{4q} x_{4i} + \mu_{i,q} \quad [7]$$

Coefficients measure the variation in productivity when a given characteristic changes, assuming that the conditional quantile of the firm remains the same. These coefficients may differ across quantiles.

[25] See Koenker and Hallock (2001).

4.2. Empirical specification

In the first equation our main interest is to test whether perceived barriers to innovate are correlated with benefiting from public support. We focus in particular in two sources of barriers that could induce firms to apply for support programs: financing constraints - whether external or internal- and difficulties derived from complying with regulations.[26] Both can be modified by policy decisions, while other barriers such as demand uncertainty or access to highly skilled labor are harder to act upon through specific innovation policies.

Financing constraints are likely to be endogenous: innovators are more likely to be aware of financing constraints than non-innovators. This would explain why previous studies often find a positive correlation between the perception of financing constraints and the likelihood of investing in innovation (Hajivassiliou and Savignac 2008, among others). To address this issue, we do not have access to an operational longitudinal panel data base, and cannot use lagged values of financing constraints. Therefore we instrument financing constraints and test for the validity of the assumption of exogeneity in the equation for public support. We use the Smith-Blundell (1986) test and the Rivers-Vuong (1988) test; both involve a two-step procedure. We also restrict the sample to firms that have invested in innovation activities or have introduced some type of innovation, whether technological or non-technological. As in Mancusi and Vezzulli (2014), the idea is to exclude firms that do not innovate not because they find barriers, but because they do not believe they need to.[27]

We include firms' perception of regulations as a barrier for innovation in this equation. Our argument is the following. Governments may implement policies that have opposite effects in terms of global efficiency: some policies reduce efficiency while other may enhance it. Innovation policy might be used to some extent, and among other goals, to offset the negative effects of efficiency reducing regulations by providing support for innovation in these sectors. Other regulations may be efficiency enhancing, such as those aiming at reducing environmental externalities; governments might then use innovation policy to foster the development or adoption of technologies that enable

[26] Internal and external financing constraints are highly correlated, so a single indicator is defined (see Table A2).

[27] The number of excluded firms is 100 in traditional services, 50 in KIS and 73 in manufacturing.

firms to comply with these environmental regulations. In this case regulation and innovation policies would be complementary, while in the first case they would be conflicting from an efficiency perspective. In both cases regulated sectors might be targeted for public support for innovating. With the information we have from EDIT we cannot distinguish between efficient and inefficient regulations, but we can nevertheless test whether there is an association between regulation and allocation of public support.[28]

Low appropriability of returns generated by innovations is one of the standard arguments for market underprovision of innovations, and hence backing public support. Some innovation surveys ask firms whether the risk of imitation is substantial; others do not, in which case researchers use as a proxy some measure of patenting activity by the firm or in the industry. This measure has obvious limitations, as it proxies both the firm's stock of knowledge and its willingness -or perceived need- to protect inventions. In our specification we use a similar proxy, mostly for comparability, but the Colombian survey also allows us to use a direct measure of the ease of imitation. Both variables turn out not to be significantly correlated in our sample, hinting that they measure different phenomena.

Note that we observe whether firms obtain public funds, but not whether a firm applied for but was denied support. Estimated coefficients will then capture the net correlation between having public support and firm characteristics. We control for some features that are usually found to be associated with a firm being more inclined to innovate. These are firm size, being an exporter and the firm's productivity relative to the industry mean, the last two variables lagged one period. We do not expect ex-ante major qualitative differences across manufacturing and service industries, except that for the former exporter status is likely to be more significant, while regulations may be more relevant for services, as explained above.

Equation [2], the probability that a firm will invest in innovation, and equation [3], investment intensity, both include as independent variable the predicted probability of receiving public support. By providing funding, public support can help firms engage in

[28] Crespi, Olivari and Vargas (2016) estimate that in LAC countries as a whole allocative efficiency contributes positively to productivity in almost all manufacturing industries, its contribution is negative in construction and several service industries, suggesting mobility barriers. Blind et al. (2017) show how regulatory capture may affect innovation costs.

innovation projects, increase the breadth of existing projects and/or allow firms to keep engaged in innovation (Arqué-Castells and Mohnen 2015). We assume that the predicted probability of obtaining public support captures the strength of financing constraints faced by firms: if constrained firms with good projects are more likely to apply for and obtain public support, and we assume that the public agency is able to discriminate across applicants, then this barrier would not have a further, direct relationship with investment decisions. This strategy is also followed by Gallego et al. (2015) and Crespi et al. (2016), who use public support but not financing constraints in their specifications of the discrete and continuous investment decisions.

In addition, we assume that the binary decision to invest in innovation activities may be correlated with the firm's human capital, its previous innovation effort -capturing the degree of persistence of these activities-, relative productivity -more productive firms may obtain higher returns from innovating, as found by Aw et al. (2011)-, demand uncertainty and firm size. Investment intensity (innovation expenditures per employee) is assumed to be potentially correlated with the importance the firm gives to different sources of information, basically from market sources -suppliers and/or customers- and from research institutions -universities and public or private centers-, but not directly by firm size, as in Crespi and Zuniga (2012), Alvarez et al. (2015) and Crespi et al. (2016). We include foreign ownership and being an exporter in both equations, as the first may be a channel of international knowledge transfer, and the second may motivate innovation through the pressure of international competition.

An innovation production function, equation [4], will be estimated for each type of innovation, that is, we estimate in fact four probit equations, where the same specification is used for all. Feedback effects across dependent variables are assumed away. In this sense they are reduced forms. We assume that in addition to predicted innovation expenditure per employee, the following inputs are correlated with introducing innovations: human capital (% employees with higher education, in three intervals), and market and institutional sources of information. We also assume that public support does not directly affect the introduction of innovations beyond the indirect effect through innovation investment. In addition we control for exporting status, foreign ownership and firm size, as in Crespi and Zuniga (2012).

Finally, labor productivity (equation [5]) is assumed to be correlated with the predicted probability of introducing innovations -one type at a time, in order to avoid multicollinearity-, as well as with the firm's human capital, foreign ownership and exporting status, all lagged one period.[29] We will present and compare 2SLS and quantile regression estimates, showing the .15, .25, .50, .75 and .90 quantiles of the conditional productivity distribution. All equations include industry fixed effects.

5. Results

Access to public support

Table 4 reports our estimation results as well as the outcome of the exogeneity tests we conduct for financing constraints. We find that obtaining public support is significantly and positively correlated with perceived financing constraints for firms in manufacturing and in traditional services, but not in KIS.[30] In contrast, we find that in KIS firms that perceive regulations to be an important barrier to innovate are more likely to obtain public support. This result highlights the distinct role of regulations in services. If they respond to efficiency criteria -environmental regulations, for instance-, this outcome would suggest that public funds for innovation complement other policies. But if regulations are not efficiency enhancing, but rather create inefficiencies, then public support to innovation may just be a means to partially offset the negative effects of the former, in which case the best approach would be to revise these regulations in the first place.[31]

Ease of imitation is uncorrelated with having public support, which may reflect that this is not an important motivation for firms to apply for support, or for the agency to grant it; we cannot discriminate between these two mechanisms with the available information. Previous experience in R&D is positively correlated with access to public support in all industries, while using some type of formal intellectual property

[29] Unfortunately the EDIT surveys do not provide information on the firm's physical capital or investment.

[30] Busom et al. (2015) also find that in Spain obtaining direct public support is uncorrelated with financing constraints in services, although they do not separate KIS from other services.

[31] The OECD computes a Services Trade Restrictiveness Index (STRI) for 42 countries and reports that in the case of Colombia this index is below the average in 18 out of 22 sectors, with legal, architecture, engineering and road transport among the lowest. Telecommunications, insurance and broadcasting are at or above the mean, which means that trade related regulations in these activities could be improved. The OECD also notes that Colombia maintains some restrictions for foreigners as well as preferential treatment for Colombian inputs in the public procurement market (OECD 2015).

protection is highly significant only for KIS. Regarding the importance of firm size in accessing public support, we find that in traditional services larger firms have a higher probability of benefiting from support, but not in manufacturing or KIS. Exporter status, foreign ownership and relative productivity of the firm do not appear to be significantly associated to receiving public support in any industry.

Overall, our results regarding the allocation process suggests that on average: i) innovators in all industries face binding financing constraints and resort to public support mechanisms; ii) there is no evidence that imitation is a binding barrier; iii) regulations and intellectual property issues are relevant for KIS, and iv) most productive firms are not more likely to obtain support, either because they do not self-select into applying for it, or because public agencies on average do not discriminate across the productivity distribution of firms.

[Insert Table 4 about here]

Investing in innovation

Table 5 reports estimates for the discrete decision to undertake innovation activities (columns 1, 3 and 5), and for the continuous, censored intensity of innovation expenditures (columns 2, 4 and 6). Regarding the discrete decision, we find that lagged innovation intensity is significantly associated with the probability of deciding to invest in innovation the following year in all three industries, suggesting that there is persistence in innovation activities, as highlighted in studies for other countries (Peters 2009). Controlling for previous innovation effort, engaging in innovation activities is highly and positively correlated with public support, especially in manufacturing and KIS. This suggests that receiving public support may increase the extensive margin of innovative firms, as found in Arqué and Mohnen (2015).[32] The likelihood of carrying out innovation activities increases with firm size in all three industries, as in Gallego et al. (2015), hinting that fixed and sunk costs of innovation are present in all industries. A

[32] Our data do not allow us to perform a full evaluation exercise of public programs. Crespi et al. (2015) have evaluated the effect of programs administered by the Colombian Innovation Agency (Colciencias) using longitudinal firm-level data. This allows them to use a fixed effects identification strategy to control for selection bias. Improving or extending their work would require to have access to additional data. Our results, however, add to theirs in that ours explicitly point to the channel through which public programs contribute to increasing productivity: relaxing financing constraints for innovation activities, and regulation related hurdles.

higher level of human capital is associated with the likelihood of engaging in innovation in manufacturing firms, but we do not find it significant for services.

Conditional on deciding to invest in innovation, innovation expenditures per employee are positively correlated with obtaining public support in KIS, but not in manufacturing or in traditional services. This result differs from Gallego et al. (2015), who find that in manufacturing direct support is positively correlated with innovation expenditures.[33] This would be consistent with the fact that innovation often involves fixed costs, so public support would mostly affect the extensive rather than the intensive margin. An interesting difference between manufacturing and service firms concerns the role of foreign ownership, which is positively correlated with investment in innovative activities in manufacturing but not in KIS, even if in our sample the percentage of foreign owned firms among those with more than 50 employees in KIS is higher than in manufacturing. Differences in capital intensity and the nature of innovation across both industries might explain this result.

[Insert Table 5 about here]

Introducing different types of innovations

Estimated investment intensity is highly correlated with the probability of introducing each of the four types of innovations, as shown in Table 6. This is not a surprising result given that most firms introduce combinations of the different types at the same time. A one-percent increase in investment intensity raises the probability of introducing product innovations by 3 percentage points (pp.) in traditional services and KIS, and by about 7 pp. in manufacturing. Magnitudes are similar for product, organizational and marketing innovations in service industries, while this elasticity is slightly lower than product and process innovations in manufacturing. Alertness to market information is positively correlated with introducing all types of innovations across industries, as we would expect. Information from research institutions is less important but still significant for all but process innovations.

[33] See their results in Table 4 of their article, on page 622. Our results and theirs are not strictly comparable because of differences in sample size and composition (our sample of service firms is larger and less biased than theirs towards large firms) and empirical specifications.

Is foreign direct investment associated with the introduction of innovations in Colombia? Some studies for developed countries have found that the answer varies across industries and countries. While Peters et al. (2014) do not find evidence of a significant relationship in services in the UK or in Germany, in the case of Ireland it is positive, suggesting that distance to the productivity frontier may play a role. In our case, we find a weak, negative correlation with product innovation in Colombian traditional services, as in Gallego et al. (2015) and with marketing innovation in manufacturing, but otherwise FDI seems unrelated to the introduction of innovations.

Our estimations show that employees' skills are highly correlated with the probability of introducing all sorts of innovation in manufacturing firms, and with product innovations in traditional services. Even if they appear not to be correlated with the intensity of innovation investment in the previous stage, the actual introduction of innovations is correlated with the firm's human capital, corroborating their complementarity. Surprisingly skills are not significant for KIS, although this might be attributed to the fact that very few firms in these industries do not have qualified employees. Finally, estimates confirm that large firms are more likely to introduce all kinds of innovation in services (both traditional and KIS), in line with previous studies (Mairesse and Robin, 2009; Musolesi and Huiban, 2011; Peters et al. 2014).

[Insert Table 6 about here]

Labor productivity

Quantile regression estimates for each type of innovation, along with standard 2SLS estimates, are reported in Tables 7 to 12. We find that in manufacturing industries product, process, marketing and organizational innovations are positively correlated with productivity. Two stage least squares (2SLS) provide coefficient estimates at the mean that are slightly higher for marketing and organizational innovations than for process innovations. However 2SLS estimates hide some heterogeneity across the productivity distribution: firms at the lower tail would benefit substantially more from innovating than more productive firms, although they all do. Our results differ from those found by Crespi, Tacsir and Vargas (2016), who look at the effect of product and process innovations on labor productivity in the manufacturing sector. Using data from The World Bank Entreprise Surveys for 17 Latin American countries, they find that firms at the bottom of the distribution obtain lower returns from innovating than firms at the upper levels. Policy implications from our respective findings would thus differ; but heterogeneity across LACs in manufacturing should be investigated further before drawing any recommendations.

The picture that emerges for service industries in Colombia is different if we rely on 2SLS estimates: in both KIS and in traditional services the introduction of innovations, whether it is product, process or non-technological, appears to be unrelated to productivity. However, a closer look through quantile regression shows that in KIS product and marketing innovations increase significantly the productivity of firms in the 0.25th quantile, but not of those above it.[34] Therefore, removing barriers to innovation in low productivity firms would yield high returns. These barriers might stem from a variety of factors, including lack of competition, inefficient regulation and financing constraints. We do not find evidence that process and organizational innovations are correlated with labor productivity. Human capital, however, is always significant and higher for firms with higher productivity.

In traditional service firms the introduction of all types of innovations increases the productivity of firms at or below the median of the productivity distribution. The effect is strongest for product and marketing innovations, especially for firms at or below the median. 2SLS coefficients would underestimate again the impact of introducing innovations in services.

Also highly relevant from a policy perspective is our finding that increasing the human firms' human capital would boost the productivity of firms both in services and in manufacturing, and relatively more that of firms at the top half of the distribution. Crespi et al. (2016) also find a similar pattern for manufacturing firms in their study, and our coefficient estimates are quite similar to theirs. This suggests that limited availability of human capital is a wide-ranging hurdle for productivity growth in Colombia, where the number of engineering graduates per million inhabitants is low relative to other countries (Lederman et al. (2014)). Finer measures of human capital, such as indicators of managerial skills, would provide better insights into the bottlenecks for productivity growth, as Bartz et al. (2016) find for Eastern European

[34] The hypothesis of equality of coefficients is rejected.

countries. Finally, foreign ownership is on average positively correlated with productivity in most quantiles for all industries.

[Insert Tables 7 to 12 about here]

6. Concluding remarks

In this study we investigate two previously unexplored issues for manufacturing and service firms in Colombia: the existence of an association between perceived barriers to innovation and the allocation of public support for innovation, and the potential heterogeneity of returns to different types of innovation across the productivity distribution in each industry. We do it by extending the Crèpon-Duguet-Mairesse framework that relates innovation investment decisions, outcomes and productivity at the firm level by including an equation for the allocation of direct support and by using quantile regression methods to allow for potentially heterogeneous returns to innovation.

We find significant differences across manufacturing and service industries in several respects. The first concerns the allocation of public support for innovation. Firms that face financing constraints are more likely to benefit from public support in manufacturing and in traditional services. In knowledge intensive services (KIS), however, firms that perceive regulations to be a hurdle for innovation are more likely to have public support. This suggests that improving the financial system so that it becomes easier for innovators to obtain private funding could help promoting innovation in manufacturing or traditional services, but it might not be sufficient for KIS unless the efficiency effects of some regulations are revised.

Regarding the link between innovation and productivity, we find that in all service industries, including KIS, the introduction of all types of innovations increases productivity of firms below the median of the productivity distribution, but not of those above it. Within manufacturing innovation would result in higher productivity in all quantiles of the distribution, but again slightly more in lower quantiles. At the same time, returns to human capital are significant and increasing with productivity in all industries, suggesting that investing in human capital is private and socially profitable across the board. Our work thus contributes to the recent strand of research that examines the heterogeneous constraints and performance of firms, especially in developing and emerging countries (Paunov and Rollo, 2016).

In terms of policy implications, our results suggest that public action toward factors that hinder innovation by low productivity firms in the service industries -human capital and some regulations- could significantly contribute to increasing productivity and reducing the range of its dispersion by decreasing the weight of the lower tail. Regarding human capital, the provision of consultancy services to enhance managerial capital could be an important and promising course of action, as found in Bruhn et al. (2013) for Mexico. However, entrepreneurs and SMEs may experiment several constraints at the same time, with varying intensity, so a mix of interventions might be necessary, after first identifying more precisely the nature of these constraints. For instance, more specific information on the kind of regulations affecting knowledge intensive firms -whether they are labor or product market related- would allow a better identification of sector specific analysis of barriers to innovation. Using existing innovation surveys to introduce -at least in one wave- questions that allow better diagnostics on which to back policy initiatives could be an avenue for action, as well as the design of policy field experiments.

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Table 1. Sample composition by firm size

Number of employees	All Services	KIS	Traditional	Manufacturing
≤ 50	53.6%	60.5%	48.9%	47.0%
51-150	16.0%	14.4%	17.1%	19.4%
>150	30.4%	25.2%	34.0%	33.6%
Total	100%	100%	100%	100%

Table 2. Investment in innovation, public support and innovation output

By industry and firm size

Percentage of firms

	All services			KIS			Traditional Services			Manufacturing		
	<=50	51-150	>150	<=50	51-150	>150	<=50	51-150	150	<=50	51-150	>150
With Innovation Expenditures	18.17	35.78	43.49	17.33	41.60	41.67	18.39	31.36	44.94	18.35	35.23	45.72
Engage in R&D activities	6.61	11.84	25.21	7.45	18.24	27.5	5.91	8.23	24.07	7.05	22.73	40.79
Obtain Public Support	2.83	6.58	6.37	2.95	6.57	4.58	2.73	6.58	7.26	4.24	7.95	14.14
Introduce product innovations	9.99	20.99	25.48	8.35	21.25	29.96	11.64	19.10	22.70	10.11	19.31	37.82
Introduce process innovations	13.92	26.32	36.15	13.69	31.39	39.17	14.12	23.46	34.65	14.11	25.57	38.16
Introduce organizational innovations	12.74	26.05	36.15	12.65	31.38	37.50	12.82	23.05	35.47	12.94	25.00	34.21
Introduce marketing innovations	10.22	15.53	24.93	9.53	14.60	25.41	10.81	16.05	24.69	10.35	17.04	25.66
Introduce any innovation	22.66	40.79	50.83	20.97	43.80	51.67	24.06	39.09	50.41	23.52	39.77	55.92
Use formal IP protection	1.33	2.37	3.05	1.04	2.19	4.16	1.58	2.47	2.49	1.18	6.82	8.88
Log Sales per Employee (mean)	10.83	10.51	10.25	10.94	10.67	10.36	10.74	10.43	10.20	10.04	10.54	10.40

Source: Authors' computations with the sample described in Table A1.

Table 3. Innovation Barriers and other firm features
By industry and firm size
Percentage of firms

	KIS			Traditional			Manufacturing			All services		
	<=50	51-150	>150	<=50	51-150	150	<=50	51-150	>150	<=50	51-150	>150
					A. Innovation Barriers							
Financing Constraints: Internal	24.96	21.17	13.33	28.38	21.81	19.71	40.94	36.93	22.37	26.82	21.58	17.59
Financing Constraints: External	24.78	18.98	11.67	24.93	15.23	15.98	31.53	24.43	18.09	24.86	16.57	14.54
Internal or External	32.41	27	15.5	35.01	26.75	24.69	47.05	43.18	27.3	33.83	26.84	22.29
Demand Risk	21.84	16.06	17.08	23.91	20.99	17.63	30.35	29.54	22.7	22.97	19.21	17.45
Lack of qualified personnel	19.06	18.98	17.08	19.74	22.63	20.54	31.06	26.14	16.12	19.43	21.32	19.39
Regulation	9.53	5.84	13.33	12.68	10.7	9.54	10.82	10.79	9.21	11.25	8.95	10.8
					B. Sources of information							
Suppliers	18.44	20.55	26.67	21.08	30.97	24.54	19.35	18.29	25.13	20	26.88	25.25
Customers	26.95	28.77	25.19	24.02	19.47	25.27	21.77	29.27	28.8	25.22	23.12	25.24
Universities	5.67	4.11	7.41	6.37	7.08	10.25	0	4.87	10.47	6.09	5.91	9.31
Government	2.12	5.48	1.48	5.39	4.42	3.66	0.81	2.44	4.19	4.06	4.84	2.94
					C. Firm characteristics							
Foreign ownership	1.03	3.65	7.08	0.86	4.11	4.35	1.29	1.64	5.19	1.18	2.36	5.82
Exporter	4.68	7.3	15	9.37	8.64	11	12.47	38.07	62.17	7.24	8.16	12.32
					D. Skills							
Skills Low	11.09	0.73	3.33	7.64	1.23	0.41	5.41	1.14	0	9.21	1.05	1.39
Skills Medium	37.09	51.09	54.58	53.17	67.49	63.69	73.41	81.25	81.91	45.87	61.58	60.66
Skills High	51.82	48.18	42.08	39.19	31.28	35.89	21.18	17.61	18.09	44.93	37.37	37.95

Table 4. Access to Public Support

	Traditional Services	KIS	Manufacturing
Financing Constraints	0.0441***	0.0160	0.0612**
	(0.0139)	(0.0159)	(0.0220)
Regulations	0.0252*	0.0494***	0.0256
	(0.0162)	(0.0178)	(0.0220)
Formal IP Protection	0.0180	0.0755**	0.0368
	(0.0397)	(0.0360)	(0.0358)
Ease of Imitation	-0.0212	0.00584	-0.0228
	(0.0176)	(0.0190)	(0.0248)
Regular R&D	0.0887***	0.0594**	0.0987***
	(0.0210)	(0.0274)	(0.0253)
Exporter (t-1)	0.0134	0.0159	0.0290
	(0.0216)	(0.0262)	(0.0230)
Foreign Ownership	-0.0419	(‡)	0.00517
	(0.0385)		(0.0402)
Relative Productivity (t-1)	0.0282	-0.0227	0.0938
	(0.0308)	(0.0236)	(0.0678)
50<Size≤150	0.0562**	0.0205	0.0198
	(0.0187)	(0.0211)	(0.0299)
Size>150	0.0441**	0.0044	0.0225
	(0.0189)	(0.0202)	(0.0318)
Industry fixed effects (1 digit)	Yes	Yes	Yes
Observations	1,319	876	832
LR Chi^2	77.97***	45.74***	58.19***
Log Likelihood	-274.04	-150.20	-232.02
Pseudo R^2	0.1079	0.1321	0.114
Smith-Blundell[a] χ^2	1.88	1.25	0.16
P-value	0.17	0.26	0.69
Rivers-Vuong[b] z-statistic	1.72	1.13	0.29
P-value	0.09	0.26	0.77

Notes: Each column shows estimated average marginal effects. Estimation method: Probit. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. (‡) This variable is dropped from this equation because it predicts failure perfectly. [a,b] Tests for endogeneity, where the suspected endogenous variable is financial constraints. The instruments used are the log of firm size and the lag of sales per worker (Handlock and Pierce 2010). Under the null hypothesis the variable is exogenous.

Table 5. Probability of investing in innovation and innovation expenditure per employee

	Traditional Services		KIS		Manufacturing	
	Decision	Intensity	Decision	Intensity	Decision	Intensity
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Public Support ^{pred}	0.533**	1.062	0.786**	3.393**	1.290***	0.936
	(0.252)	(1.333)	(0.377)	(1.637)	(0.326)	(1.235)
Innovation Intensity (t-1)	0.104***	0.620***	0.117***	0.571***	0.107***	0.469***
	(0.0062)	(0.0487)	(0.00879)	(0.0654)	(0.0078)	(0.0545)
Exporter (t-1)	-0.00874	0.0183	-0.0342	-0.424	-0.0327	-0.552**
	(0.0499)	(0.337)	(0.0703)	(0.448)	(0.0490)	(0.253)
Foreign Ownership	0.139*	0.390	-0.0401	-0.0019	0.0811***	0.875**
	(0.0783)	(0.491)	(0.100)	(0.621)	(0.0085)	(0.445)
Information: market		0.0185		0.146		0.284
		(0.190)		(0.267)		(0.246)
Information: institutions		-0.206		-0.262		0.178
		(0.215)		(0.315)		(0.267)
Skills Medium (t-1)	-0.167	-0.514	0.0671	-0.645	0.462*	1.635
	(0.109)	(0.616)	(0.119)	(0.678)	(0.243)	(1.727)
Skills High (t-1)	-0.189*	-0.644	0.0420	-0.358	0.426*	2.174
	(0.105)	(0.630)	(0.110)	(0.681)	(0.234)	(1.737)
Formal IP Protection	0.164*		-0.0412		-0.0059	
	(0.0958)		(0.138)		(0.0914)	
Demand Risk	0.0644**		-0.0328		-0.0127	
	(0.0265)		(0.0356)		(0.0373)	
Relative Productivity (t-1)	0.0387		-0.205*		-0.364**	
	(0.0868)		(0.105)		(0.180)	
Size	0.0607***		0.0771***		0.0582***	
	(0.0105)		(0.0126)		(0.0204)	
Constant		2.487***		2.784***		1.085
		(0.764)		(0.916)		(1.775)
Industry fixed effects (1 digit)	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,319		876		832	
Censored Observations	904		625		559	
Uncensored observations	415		251		273	
Wald Test of Independence (rho=0)	39.47***		31.62***		12.59***	

Notes: Each column shows the estimated average marginal effect. ^{pred} denotes predicted Public Support. Estimation method: Heckit maximum likelihood. Bootstrapped standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Introduction of Innovations by type and industry

Probit marginal effects

	Product			Process			Marketing			Organizational		
	Traditional	KIS	Manuf.	Traditional	KIS	Manuf.	Traditional	KIS	Manuf.	Traditional	KIS	Manuf.
Innovation Intensity^{pred}	0.0392***	0.0334***	0.0714***	0.0535***	0.0446***	0.0793***	0.0379***	0.0232***	0.0482***	0.0385***	0.0306***	0.0572***
	(0.0048)	(0.0061)	(0.0073)	(0.0051)	(0.0071)	(0.00755)	(0.0047)	(0.0067)	(0.0081)	(0.0055)	(0.0071)	(0.0089)
Information: market	0.165***	0.165***	0.130***	0.213***	0.209***	0.186***	0.173***	0.171***	0.149***	0.229***	0.234***	0.195***
	(0.0192)	(0.0237)	(0.0274)	(0.0191)	(0.0257)	(0.0256)	(0.0179)	(0.0268)	(0.0281)	(0.0181)	(0.0237)	(0.0285)
Information: institutions	0.0813**	0.0706*	0.0626	0.0280	0.0623	0.0418	0.100***	0.0733*	0.0964**	0.118***	0.0925*	0.0689
	(0.0266)	(0.0325)	(0.0356)	(0.0306)	(0.0416)	(0.0368)	(0.0246)	(0.0338)	(0.0311)	(0.0288)	(0.0393)	(0.0388)
Exporter (t-1)	-0.0110	0.0166	0.0515*	-0.00752	0.0268	0.0278	-0.0252	0.0435	-0.00247	-0.0222	-0.0207	0.0233
	(0.0303)	(0.0346)	(0.0252)	(0.0329)	(0.0423)	(0.0287)	(0.0282)	(0.0370)	(0.0270)	(0.0309)	(0.0439)	(0.0281)
Foreign Ownership	-0.130*	-0.0268	-0.0100	-0.0356	-0.0381	-0.0759	-0.0711	0.0834	-0.126*	-0.0880	-0.0839	-0.0383
	(0.0615)	(0.0489)	(0.0416)	(0.0558)	(0.0612)	(0.0510)	(0.0497)	(0.0516)	(0.0636)	(0.0631)	(0.0560)	(0.0600)
Formal IP Protection	0.114*	0.0250	0.0577	0.0373	0.0601	0.0452	0.103*	0.0121	0.119**	0.0556	0.00172	0.145**
	(0.0512)	(0.0547)	(0.0459)	(0.0500)	(0.0751)	(0.0523)	(0.0436)	(0.0572)	(0.0420)	(0.0508)	(0.0688)	(0.0487)
Skills Medium (t-1)	0.882***	0.00526	0.511***	-0.0287	0.000167	0.677***	-0.0894*	-0.0469	0.614***	-0.0109	0.0628	0.767***
	(0.0609)	(0.0362)	(0.0506)	(0.0589)	(0.0401)	(0.0542)	(0.0431)	(0.0387)	(0.0489)	(0.0638)	(0.0413)	(0.0552)
Skills High (t-1)	0.893***	-0.0125	0.487***	-0.0561	-0.0180	0.632***	-0.0989*	-0.0746	0.557***	-0.00851	0.0269	0.761***
	(0.0613)	(0.0357)	(0.0569)	(0.0604)	(0.0403)	(0.0616)	(0.0443)	(0.0381)	(0.0541)	(0.0644)	(0.0409)	(0.0600)
Size	0.00913*	0.0245***	0.0197*	0.0315***	0.0240***	0.00625	0.0216***	0.0120*	0.00613	0.0323***	0.0273***	0.0059
	(0.0045)	(0.0047)	(0.0078)	(0.0049)	(0.0054)	(0.0088)	(0.0045)	(0.0052)	(0.0086)	(0.0049)	(0.0049)	(0.0085)
Industry fixed effects	Yes	Yes	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes	-
Observations	1319	876	832	1319	876	832	1319	876	832	1319	876	832
Wald c2	672.89***	289.34***	1887.68***	410.81***	263.15***	2010.83***	333.41***	186.14***	27885.05***	382.62***	293.65***	3453.1
Log pseudo likelihood	-433.68	-254.61	-275.32	-492.37	-307.46	-291.22	-406.75	-276.41	-275.21	-485.88	-297.20	-315.83
Pseudo R2	0.293	0.380	0.387	0.328	0.372	0.395	0.338	0.270	0.304	0.331	0.378	0.317

Notes: ^{pred} denotes predicted innovation expenditure per employee. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Bootstrapped standard errors in parenthesis.

Table 7. Traditional Services: Product and process innovation and Productivity

	Product						Proccess					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
$Innovation^{pred}$	0.286	0.887***	0.643***	0.299***	0.114	-0.00873	0.134	0.338	0.349***	0.212**	0.0694	-0.00612
	(0.162)	(0.274)	(0.138)	(0.0978)	(0.137)	(0.339)	(0.143)	(0.286)	(0.132)	(0.0890)	(0.138)	(0.236)
Exporter (t-1)	0.679***	0.379	0.540***	0.540***	0.819***	1.136***	0.683***	0.291	0.614***	0.565***	0.832***	1.136***
	(0.143)	(0.264)	(0.204)	(0.114)	(0.232)	(0.355)	(0.146)	(0.393)	(0.187)	(0.130)	(0.249)	(0.394)
Foreign Ownership	0.686*	0.468	0.673*	0.696***	0.642*	0.843	0.655*	0.341	0.655*	0.658***	0.627**	0.843
	(0.291)	(0.382)	(0.348)	(0.167)	(0.344)	(0.606)	(0.259)	(0.372)	(0.389)	(0.177)	(0.257)	(0.720)
Skills (t-1)	0.429***	0.428***	0.319***	0.324***	0.395***	0.581***	0.436***	0.524***	0.333***	0.356***	0.404***	0.584**
	(0.102)	(0.130)	(0.121)	(0.0851)	(0.0603)	(0.179)	(0.0980)	(0.139)	(0.0598)	(0.0823)	(0.126)	(0.241)
Constant	11.96***	10.41***	10.82***	11.65***	12.72***	14.65***	11.96***	10.38***	10.79***	11.60***	12.71***	14.64***
	(0.180)	(0.258)	(0.177)	(0.200)	(0.245)	(0.841)	(0.218)	(0.262)	(0.0920)	(0.240)	(0.263)	(0.931)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.332	0.118	0.140	0.222	0.283	0.271	0.332	0.114	0.137	0.222	0.282	0.271

Notes: ^{Pred} denotes predicted probability of introducing an innovation. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Bootstrapped standard errors in parentheses. Pseudo R^2 report a measure of fit for quantiles.

Table 8. Traditional Services: Marketing and organizational innovation and Productivity

	Marketing						Organizational					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
$Innovation^{pred}$	0.255	0.799**	0.595***	0.263**	0.0987	-0.00791	0.0460	0.312	0.326***	0.154	0.0619	-0.154
	(0.185)	(0.323)	(0.145)	(0.106)	(0.144)	(0.271)	(0.153)	(0.241)	(0.115)	(0.0978)	(0.121)	(0.261)
Exporter (t-1)	0.679***	0.372	0.545**	0.536***	0.842***	1.136*	0.689***	0.283	0.613**	0.557***	0.807***	1.083**
	(0.175)	(0.270)	(0.214)	(0.164)	(0.292)	(0.622)	(0.158)	(0.382)	(0.250)	(0.144)	(0.257)	(0.466)
Foreign Ownership	0.662*	0.367	0.667**	0.661***	0.830***	0.843	0.669*	0.417	0.658*	0.678**	0.626*	0.782
	(0.269)	(0.478)	(0.278)	(0.218)	(0.181)	(0.672)	(0.270)	(0.366)	(0.352)	(0.263)	(0.359)	(0.805)
Skills (t-1)	0.435***	0.455***	0.324***	0.352***	0.405***	0.581***	0.434***	0.538***	0.335***	0.351***	0.407***	0.541***
	(0.0855)	(0.141)	(0.0842)	(0.0690)	(0.0769)	(0.163)	(0.0867)	(0.125)	(0.0977)	(0.0885)	(0.123)	(0.206)
Constant	11.97***	10.47***	10.83***	11.62***	12.72***	14.65***	11.99***	10.39***	10.81***	11.61***	12.71***	14.70***
	(0.189)	(0.269)	(0.188)	(0.263)	(0.380)	(0.866)	(0.228)	(0.231)	(0.134)	(0.231)	(0.264)	(1.038)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.332	0.118	0.140	0.222	0.283	0.271	0.332	0.113	0.137	0.221	0.282	0.271

Notes: as in Table 7

Table 9. KIS: Product and process innovation and Productivity

	Product						Proccess					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
Innovation^{pred}	0.0778	0.355	0.455**	0.0534	-0.0857	-0.0899	0.00582	0.260	0.240	0.0233	-0.106	-0.117
	(0.225)	(0.343)	(0.206)	(0.201)	(0.318)	(0.306)	(0.187)	(0.248)	(0.149)	(0.184)	(0.298)	(0.338)
Exporter (t-1)	0.396*	0.0981	0.244	0.576**	0.280	1.097**	0.401*	0.143	0.208	0.576**	0.268	1.098*
	(0.202)	(0.338)	(0.317)	(0.250)	(0.250)	(0.553)	(0.192)	(0.280)	(0.305)	(0.238)	(0.287)	(0.616)
Foreign Ownership	0.514**	0.746**	0.589*	0.297	0.673	0.178	0.525*	0.752***	0.575***	0.304	0.689*	0.201
	(0.171)	(0.321)	(0.340)	(0.348)	(0.486)	(0.309)	(0.223)	(0.223)	(0.194)	(0.313)	(0.380)	(0.325)
Skills (t-1)	0.687***	0.632***	0.546***	0.487***	0.950***	0.870***	0.687***	0.619***	0.585***	0.492***	0.952***	0.872***
	(0.121)	(0.103)	(0.124)	(0.0893)	(0.169)	(0.272)	(0.108)	(0.136)	(0.140)	(0.125)	(0.162)	(0.130)
Constant	10.18***	8.914***	9.514***	10.21***	10.86***	11.83***	10.20***	8.910***	9.524***	10.20***	10.86***	11.83***
	(0.101)	(0.160)	(0.113)	(0.0831)	(0.136)	(0.207)	(0.0817)	(0.141)	(0.119)	(0.0978)	(0.131)	(0.232)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.178	0.085	0.078	0.095	0.111	0.125	0.178	0.085	0.077	0.095	0.111	0.126

Notes: ^{Pred} denotes predicted probability of introducing an innovation. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Bootstrapped standard errors in parentheses. Pseudo R^2 reports a measure of fit for quantiles.

Table 10. KIS: Marketing and organizational innovation and Productivity

	Marketing						Organizational					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
Innovation^{pred}	0.159	0.950**	0.484**	0.120	-0.106	-0.109	-0.0401	0.203	0.172	0.000807	-0.130	-0.263
	(0.239)	(0.413)	(0.231)	(0.291)	(0.399)	(0.444)	(0.161)	(0.290)	(0.193)	(0.187)	(0.282)	(0.276)
Exporter (t-1)	0.390	-0.140	0.215	0.574**	0.285	1.099	0.402**	0.114	0.204	0.576***	0.267	1.038*
	(0.230)	(0.306)	(0.264)	(0.238)	(0.320)	(0.670)	(0.148)	(0.295)	(0.276)	(0.192)	(0.216)	(0.534)
Foreign Ownership	0.481	0.498*	0.497**	0.278	0.688*	0.195	0.530*	0.834***	0.614*	0.316	0.711*	0.181
	(0.259)	(0.280)	(0.242)	(0.335)	(0.371)	(0.395)	(0.230)	(0.312)	(0.366)	(0.495)	(0.380)	(0.242)
Skills (t-1)	0.688***	0.703***	0.595***	0.488***	0.947***	0.867***	0.687***	0.635***	0.601***	0.504***	0.956***	0.872***
	(0.119)	(0.154)	(0.136)	(0.116)	(0.152)	(0.202)	(0.115)	(0.151)	(0.143)	(0.0938)	(0.206)	(0.283)
Constant	10.18***	8.784***	9.518***	10.20***	10.86***	11.83***	10.21***	8.934***	9.528***	10.20***	10.87***	11.89***
	(0.104)	(0.154)	(0.126)	(0.0888)	(0.118)	(0.273)	(0.116)	(0.145)	(0.136)	(0.0958)	(0.134)	(0.218)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.178	0.086	0.078	0.095	0.111	0.125	0.178	0.084	0.077	0.095	0.111	0.126

Notes: as in Table 7

Table 11. Manufacturing: Product and process innovation and Productivity

	Product						Proccess					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
$Innovation^{pred}$	0.777***	1.087***	0.750***	0.855***	0.672***	0.656***	0.704***	0.984***	0.692***	0.584***	0.588***	0.601***
	(0.173)	(0.342)	(0.174)	(0.208)	(0.113)	(0.213)	(0.180)	(0.203)	(0.143)	(0.112)	(0.127)	(0.205)
Exporter (t-1)	0.679***	0.446***	0.582***	0.794***	0.857***	0.672***	0.719***	0.495***	0.613***	0.848***	0.888***	0.726***
	(0.0835)	(0.150)	(0.131)	(0.106)	(0.0778)	(0.126)	(0.0857)	(0.188)	(0.104)	(0.0830)	(0.0664)	(0.127)
Foreign Ownership	0.669***	0.567*	0.411	0.619**	0.850***	0.540	0.734***	0.671**	0.443	0.823***	0.958***	0.625
	(0.165)	(0.300)	(0.276)	(0.256)	(0.190)	(0.474)	(0.205)	(0.292)	(0.313)	(0.273)	(0.216)	(0.547)
Skills (t-1)	0.452***	0.396***	0.267**	0.347***	0.548***	0.599***	0.456***	0.391***	0.283**	0.336***	0.542***	0.630***
	(0.0928)	(0.109)	(0.105)	(0.0819)	(0.0806)	(0.149)	(0.0839)	(0.140)	(0.125)	(0.0916)	(0.105)	(0.154)
Constant	9.695***	8.738***	9.220***	9.707***	10.24***	10.96***	9.669***	8.703***	9.206***	9.702***	10.24***	10.92***
	(0.0562)	(0.139)	(0.0540)	(0.0391)	(0.0674)	(0.130)	(0.0569)	(0.122)	(0.0479)	(0.0266)	(0.0707)	(0.140)
Industry fixed effects	-	-	-	-	-	-	-	-	-	-	-	-
R-squared	0.192	0.056	0.077	0.136	0.175	0.138	0.192	0.057	0.077	0.135	0.173	0.137

Notes: as in Table 7

Table 12. Manufacturing: Marketing and organizational innovation and Productivity

	Marketing						Organizational					
	(1) 2SLS	(2) Q=0.15	(3) Q=0.25	(4) Q=0.50	(5) Q=0.75	(6) Q=0.90	(7) 2SLS	(8) Q=0.15	(9) Q=0.25	(10) Q=0.50	(11) Q=0.75	(12) Q=0.90
$Innovation^{pred}$	0.936***	1.175***	0.779***	0.876***	0.821***	0.753*	0.796***	1.107***	0.751***	0.751***	0.674***	0.666**
	(0.184)	(0.359)	(0.186)	(0.226)	(0.125)	(0.403)	(0.196)	(0.276)	(0.146)	(0.204)	(0.118)	(0.321)
Exporter (t-1)	0.727***	0.611***	0.676***	0.868***	0.919***	0.732***	0.712***	0.512***	0.660***	0.830***	0.890***	0.692***
	(0.105)	(0.157)	(0.114)	(0.0942)	(0.0764)	(0.172)	(0.0813)	(0.181)	(0.0841)	(0.0933)	(0.0814)	(0.142)
Foreign Ownership	0.787***	0.401	0.398	0.547*	0.986***	0.827	0.709***	0.277	0.272	0.392	0.959***	0.845
	(0.175)	(0.504)	(0.350)	(0.322)	(0.298)	(0.610)	(0.191)	(0.375)	(0.282)	(0.292)	(0.315)	(0.575)
Skills (t-1)	0.478***	0.408***	0.337***	0.364***	0.593***	0.689***	0.448***	0.349***	0.252***	0.329***	0.553***	0.657***
	(0.0881)	(0.150)	(0.112)	(0.116)	(0.0875)	(0.199)	(0.0913)	(0.131)	(0.0897)	(0.119)	(0.122)	(0.210)
Constant	9.673***	8.724***	9.224***	9.698***	10.21***	10.96***	9.668***	8.716***	9.216***	9.697***	10.23***	10.95***
	(0.0516)	(0.130)	(0.0417)	(0.0289)	(0.0431)	(0.147)	(0.0653)	(0.116)	(0.0647)	(0.0439)	(0.0750)	(0.157)
Industry fixed effects	-	-	-	-	-	-	-	-	-	-	-	-
R-squared	0.192	0.049	0.072	0.130	0.171	0.135	0.192	0.049	0.073	0.130	0.170	0.135

Notes: as in Table 7

Appendix

Table A1: Sample Composition

CIIU Revision 3 A.C.	Division	Activities	Inclusion Parameters	Number of firms
		KIS		954
K Real estate, renting and business activities	72, 73	Computing and R&D services	>20 employees	406
I Transport, storage, communications	60.2, 60.4, 62, 64.1, 64.2	Transportation , post, and telecommunications	>20 employees	354
J Financial intermediation	65.11, 65.12, 66, 67	Banking activities	CENSUS	194
		Traditional Services		1,419
E Electricity, gas and water supply	40, 41	Electricity, gas and water supply	>20 employees	118
G Wholesale and retail trade; reparation of equipment	50, 51, 52	Wholesale and retail trade; reparation of equipment	>50 employees; or sales >COP$5,000	794
H Hotels and restaurants	55.1, 55.2	Hotels and restaurants	>40 employees; or sales >COP$3,000	185
M, N Education, health and social services	80, 85	Education (private) Health and social services[a]	>20 employees; or sales>COP$1,000	189
O Other community and social and personal services	90-92.1	Entertainment, film, TV industries	>20 employees; or sales>COP$1,000	133
		Manufacturing		
D	15-37	Manufacturing	> 10 employees	905
		TOTAL		3,278

Notes: [a] Health services include only hospitals.
Source: Survey of Innovation and Technological Development in Services EDITS-III (2010-2011) and Manufacturing EDIT IV (2009-2010). Sales are in million Colombian pesos (COP) of 2009.

Table A2: Definition of variables

Variable Name	Variable Definition	Period of Time
Productivity	Sales per employee (in logs)	t, t-1
Relative Productivity	A measure of productivity distance between firm i and the mean of its industry. Each firm's labor productivity in t-1 is divided by the average productivity of its industry.	t, t-1
Investment Intensity	Total Innovation expenditures per employee (in logs)	t, t-1
Process Innovation	Dummy: 1 if the firm reports having introduced new or significantly improved production processes	p
Product Innovation	Dummy: 1 if the firm reports having introduced new or significantly improved products	p
Marketing Innovation	Dummy: 1 if the firm reports having introduced marketing innovations	p
Organizational innovation	Dummy: 1 if the firm reports having introduced organizational innovations	p
Foreign ownership	Dummy: 1 if foreign owners have at least 40% of the ownership in the firm.	p
Exporter	Dummy: 1 if the firm has positive exports	t, t-1
R&D	Dummy: 1 if the firm engaged in R&D activities in year t	t, t-1
Regular R&D	Dummy: 1 if firm engaged in R&D every year	t, t-1
Public Support	Dummy: 1 if the firm received local or regional funding for innovation projects	p
Innovation Barriers		
Financing constraints	Dummy: 1 if the firm reported lack of funds, whether internal or external, as a barrier of high importance	p
Ease of imitation	Dummy: 1 if the firm reported ease of imitation by third parties to be an important barrier to innovate	p
Demand risk	Dummy: 1 if the firm considered demand uncertainty for innovations to be a barrier of high importance	p
Lack of qualified personnel	Dummy: 1 if the firm reported lack of qualified personnel to be a barrier of high importance	p
Regulation	Dummy: 1 if the firm reported regulations as barrier to be of high importance to innovation	p
Formal IP Protection	Dummy: 1 if the firm uses registration of design patterns, trademarks or copyright to protect inventions or innovations	p
Information: Market	Dummy: 1 if information from suppliers or from customers was of high importance for the firm	p
Information: Institutions	Dummy: 1 if information from universities or other higher education, government or private nonprofit institutes was of high importance for the firm	p
Skills Low	Dummy: 1 if the firm has no employees with higher education degree	t, t-1
Skills Medium	Dummy: 1 if the firm has a positive share of employees with higher education but below 40%.	t, t-1
Skills High	Dummy: 1 if the firm has more than 40% of employees with higher education	t, t-1
Firm size	Natural log of the number of employees	t, t-1
Industry dummies	Dummy variables are defined for each industry: five for traditional services, three for KIS (see Table A1).	p

Note: p means that the corresponding survey question refers to the whole two-year period; t, t-1 means that the variable is available for each year.

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