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Product Innovation, Research and Development and Technology Acquisition: A Case Study of the Industrial Sector in Colombia

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Abstract: *There has been a steady increase in the number of studies investigating the determinants of product innovation in the industrial sectors of emerging economies. This research analyses the relationship between Research and Development (R&D) activities and technology acquisition on the one hand, and product innovation in the industrial sector in Colombia on the other with respect to firm size and high-tech and low-tech firms. We used data from the Colombian National Administrative Department of Statistics for the period 2003 to 2012. The results show that both R&D activities and technology acquisition foster product innovation but the former has a stronger impact. Small and low-tech firms rely more on co-operation agreements while large high-tech firms depend on their formal R&D infrastructure. Based on these findings, key industrial policy implications are discussed.*

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1. Introduction

Development is a process of transforming a country's economic structure towards the production and export of more complex products' (Felipe *et al.*, 2012: 36). A society's capacity to generate and assimilate technological shifts has become acknowledged as a central contributory factor to prosperity. In recent years, an increasing number of studies has examined

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the determinants of product innovation in the industrial sectors of emerging economies but there has been little that has been published on Colombia. This paper contributes to the body of literature on the relationship between Research and Development (R&D) activities and technology acquisition on the one hand, and product innovation in the industrial sector on the other. It will be based on firm size and level of technology. According to the Oslo Manual (OECD 2005, 48), a 'product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses'.

The measurement of innovation and its subsequent impact is one of the central challenges that scholars studying technological change have grappled with since Joseph Alois Schumpeter's (1912; 1939; 1942) pioneering work on innovation as the source of the evolution of socio-economic systems, which Schumpeter referred to as *Entwicklung*. Thus, the identification and measurement of determinants of innovation has improved our understanding of the relationship between the variables that can promote or inhibit innovation. A fruitful theoretical legacy derived from the study of endogenous growth models has resulted in manifold ways to measure innovation, its impact, and its outcomes.

Using data from the Colombian National Administrative Department of Statistics (*DANE*)[1], this paper identifies the determinants of product innovation in Colombia, a robust and growing market economy in South America pursuing a liberal trade regime. The economic landscape that shapes Colombia's export sector fuelled by free trade agreements (FTAs), and its growing ties to the countries making up the Pacific Alliance with a clear orientation towards the Asia-Pacific region (Nolte and Wehner 2014: 173), promise the Colombian industrial sector and its innovative capacity a special role in the country's economic development trajectory.

That the manufacturing sector contracted during the period 2007-2012 relative to the extractive sector in terms of its contribution to the GDP (Rudas 2014, 2; Rodrik 2015) highlights the need for more studies on Colombia, especially pertaining to small and medium sized enterprises (SMEs). It is worth bearing in mind that 'a fully-industrialised nation is characterised by a well-developed and mature technological base […] propelled by vibrant and self-sustaining innovative activity' (Narayanan and Lai 2000: 436).

Statistical data used for this research was gleaned from five Innovation Surveys (CIS)[2] in Colombia focusing on the manufacturing sector between 2003 and 2012 (DANE 2005; 2010a; 2010b; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b). The Oslo Manual (OECD 1997; 2005) served as a guide for data collection and as methodology for interpretation of these surveys. This article investigates two factors that enhance innovation namely, internal

R&D activities and technology acquisition (TA). Both inputs shape product innovation. This research determines how these two variables, considered as "inputs", affect companies of different sizes and at different technological levels. We consider as "outputs" the generation of operative knowledge or (product) innovation.

This article is structured into six sections. The first section is an introduction to the study while the second section examines innovations in Colombia and recent trends in that field. Literature review on determinants of product innovation is tackled in the third section while the fourth section presents data and methodology of this research. Results and main findings are examined in section five while the last section concludes, summarises and highlights key industrial policy implications.

2. The Innovation Environment in Colombia

The Colombian National Innovation System (CNIS) follows the traditional theoretical approximation introduced by Lundvall (1995a; 1995b) and Johnson (1995) that envisages interactive learning, knowledge, and innovation generation as the main goals of a National Innovation System (NIS). In other words, the NIS is a set of structural and institutional interactions that generate, select and spread innovation within a society. Additionally, institutional support the government provides is vital to establishing and improving the system. In this order of ideas, the CNIS considers the production of knowledge as the main outcome supporting innovation. Therefore, the increase or decrease of knowledge depends on the quality of technological learning processes. The better the technological learning processes of all the agents that make up the CNIS, the more sound the outcome in terms of knowledge production and generation of innovation. Innovation is understood as a process of generating knowledge that directly impacts on the production, organisation and markets embedded in the society.

The consolidation of the CNIS is strongly linked to *Colciencias*[3], the Colombian state agency that finances, promotes, coordinates and ensures scientific activities are more effective. Some of the key milestones of the evolution of the CNIS include Law 29 introduced in 1990 marking a watershed moment. It cemented *Colciencias*'s role as the key driver of knowledge in Colombia. For the first time, the government sought to promote advancement of science and technology activities, incorporating them into economic and social development plans. From the time Law 29 came into force, it fostered new strategic alliances between universities, firms and government as the common and expeditious way of setting the research agenda and introduce labour innovations. This law also created tributary and tax incentives with the purpose of enhancing investment in new technologies and the promotion of technology transfers.

Another important milestone in Colombia's history of science, technology, and innovation (STI) activities was reached in 1994 with the publication of the document *CONPES* 2739[4] (DNP 1994) that consolidated the activities of CNIS. This document stated that the CNIS is a collective and interactive model of learning, accumulation and knowledge application in firms, unions, specialised research centres, training centres, universities, consultancies, financial institutions, and governmental agencies. The purpose of *CONPES* 2739 was to strengthen innovation capacity and competitiveness in order to achieve sustainable economic and social development.

In 2009, Law 1286 came into force that governed STI activities in Colombia. This law is the latest contribution by Colombian policy-makers to buttress the CNIS and strengthen *Colciencias* to achieve a sustained model of production based on STI. The ultimate aim is to add value to products and services as well as encourage the development and competitiveness of the Colombian industrial sector. The main challenge facing the CNIS is to consolidate the social capital derived from the association of the system's different components. Since the 1990s, Colombia has faced intense global competition that pushed Colombian policy-makers to improve and scale up innovation activities and technological innovation as key national competitive strategies.

The first step was the introduction of the Colombian Innovation Survey (CIS) by the government. A survey was carried out in 1996 on 885 industrial firms. In 2003, the Colombian government conducted the second CIS with a much increased sample size, measuring outcomes in innovation and technological activities within the Colombian industrial sector. Colombia has now concluded a total of six CIS in the industrial sector and three CIS in the services sector. The statistical impacts the CIS have generated have had strong and positive repercussions for Colombia's STI activity measurement making the quality of data more robust. The considerable time lag between the first and subsequent surveys can be explained by severe political instabilities Colombia endured during that period, especially in the 1990s and early 2000s, resulting in the diversion of public spending from STI activities towards strengthening state security apparatus.

To get an idea of the size of Colombia as a country, Tables 1, 2 and 3 present some comparative statistics with other Ibero-American countries.

Table 1: Colombian indicators compared to middle and high-Income Ibero-American countries.

COUNTRY	POPULATION (million, 2012)[1]	GDP (billion US$, 2012)[2]	PATENTS APPLICATIONS (2011)[3]	
Colombia	48	370	Residents: Non-residents:	184 1,771
Brazil	199	2,253	Residents: Non-residents:	7,764 24,001
Spain	47	1,322	Residents: Non-residents:	3,398 245,168
Chile	17	270	Residents: Non-residents:	339 2,453
Peru	30	204	Residents: Non-residents:	40 1,129
Mexico	121	1,178	Residents: Non-residents:	1,065 12,990

Sources: [1.] World Bank (2013a); [2.] World Bank (2013b); [3.] RYCIT (2012a)

With 48 million inhabitants, Colombia is the third largest Latin American country by population after Brazil and Mexico. According to the World Bank classification (2012), Colombia is an "upper-middle-income-economy". Yet, that nation's progress in Intellectual Property (IP) activities – using patent production as a proxy of IP activities – is rather dismal lags behind Brazil and Mexico.

Table 2: R&D spending as a percentage of GDP – A comparison of some middle and high-income Ibero-American countries.

COUNTRY	2005	2006	2007	2008	2009	2010	2011
Colombia	0.14%	0.14%	0.17%	0.18%	0.17%	0.18%	0.18%
Brazil	0.97%	1.00%	1.09%	1.11%	1.16%	1.16%	1.20%
Spain	1.12%	1.19%	1.26%	1.35%	1.39%	1.39%	1.33%
Chile	n/a	n/a	0.32%	0.39%	0.43%	0.44%	n/a
Peru*	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mexico	0.41%	0.37%	0.37%	0.41%	0.44%	0.47%	0.45%

Source: RYCIT (2012b)
*Data for Peru are not available for this period.

Colombia's spending in R&D activities amounted to a mere 0.19% of GDP in 2010 compared with whereas Brazil which invested an average of 2.3% of GDP into innovation between 2003 and 2008 (see Table 2).

Table 3: Scientific articles registered at Science Citation Index – A comparison of some middle and high-income Ibero-American countries.

COUNTRY	2005	2006	2007	2008	2009	2010	2011
Colombia	950	1,115	1,239	2,184	2,386	2,798	3,167
Brazil	18,765	20,858	23,109	31,903	34,243	36,155	39,105
Spain	34,846	37,639	40,594	45,130	48,939	51,339	55,209
Chile	3,262	3,564	3,559	4,251	4,952	5,162	5,684
Peru	407	452	593	673	761	766	788
Mexico	6,807	6,504	8,501	9,637	9,778	10,171	11,069

Source: RYCIT (2012c)

In terms of high quality publications such as scientific articles, Colombia's effort during the period 2005-2011 can be seen in Table 3 which shows production more than tripled but yielded merely a twelfth of the output of Brazil, which has a population four times the size of Colombia.

3. Conceptual Framework: Product Innovation, R&D, and Technology Acquisition

Innovation is an instructive yardstick of a firm's economic achievements as well as national and international competitiveness. In order to fully exploit current export and manufacturing opportunities, the industrial sector faces significant innovation challenges, especially with respect to the diversification and improvement of product portfolio. After all, 'what you export matters' (Hausmann *et al.,* 2007: 1), and there is ample agreement that enterprises: 'introducing product […] innovations are ex-post more likely to export' (Bratti and Felice 2012, 1559; Fafchamps *et al.,* 2010; Cassiman and Golovko 2011; Liu and Buck 2007; Salomon and Shaver 2005; Roper and Love 2002; Basile 2001). In other words, successful innovators tend to be successful exporters.

Schumpeter's (1883-1950) pioneering work identified innovation as the central source of technological, cultural and economic change (Dosi, 1988, 1163). Schumpeter (1942) was the first thinker to intuitively point out the necessity for monopoly to generate innovation and to establish a positive relationship between the size of the firm and its innovative activities, i.e. the bigger the firm, the greater its innovation activities. Larger firms benefit from economies of scale, warranting sizeable investments for the establishment of: 'formal R&D infrastructure [although this] view has since been challenged even in manufacturing' (Narayanan and Parvin Hosseini, 2014, 101; Ács and Audretsch, 1990). For example, Ács and Audretsch (1988) demonstrated that small firms are more innovation-intensive than large ones since, for the most part, small firms face 'fewer rigidities to hinder the introduction of the innovation' (Vega-Jurado *et al.,* 2008: 617).

De Jong and Vermeulen (2004: 20) found that in a sample of small firms in the Netherlands 'inter-firm co-operation' forcefully propels 'product introductions', which can be explained by the fact that, owing to the capital intensive nature of the manufacturing sector, small companies are better off collaborating with others to reduce their financial commitment. However, the results of recent studies are ambiguous. Some validate the hypothesis that links a larger firm size and industries having high technological input with better innovation while others contradict it (Vega-Jurado *et al.*, 2008). For example, Oerlemans et al. (1998) found that in the manufacturing sector in the Netherlands, R&D intensity was a key factor only for science-based and specialised supplier firms.

Schumpeterian thought has set the stage for important scientific analyses to establish the determinants of innovation that use firm size and market structure as key variables (Scherer and Ross, 1990). Nevertheless, Schumpeter failed to differentiate between diverse kinds of innovations, products, processes, organisational and market innovations. Regarding the significance of innovation as a key component driving the technology intensive phase in a country undergoing economic development, as in 'latecomers' such as Colombia, it is important to note that economic historians such as Gerschenkron (1962) have stressed the: 'considerable effort and organizational and institutional change [required] to succeed' (Fagerberg *et al.*, 2010, 2).

Interestingly, Gerschenkron sought 'to analyze rather than minimize the role of the state in development', which is noteworthy with respect to the evolution of the CNIS (Gootenberg, 2001: 57). Gerschenkron also argued that 'new and dynamic industries in developing countries can most readily catch up' (Hou and Mohnen, 2013: 354). Emerging economies are able to apply contemporary knowledge much more cheaply 'through [licenses], inward investment and the recruitment of skilled people', and firms in aspirational economies do not have to face the unpredictability inherent in 'opening up entirely new markets' (Varblane *et al.*, 2012: 41). Yet, Bell and Pavitt (1997) claim that successful catch-up requires good absorption of foreign knowledge, 'active learning policies [and] a properly working innovation system' (Varblane *et al.*, 2012: 41).

Following Schumpeter, many schools of thought affirmed the importance of measuring innovation. Studies based on the "Solow residual" concept (Solow, 1956), recognises that not only do rates of factor accumulation account significantly for economic growth, but aspects emerging from the inside of the residual of the production function such as education, knowledge generation and innovation also play a central role. Solow's findings provided the base for studies that emphasised endogenous forces such as entrepreneurial activities where innovation efforts are the major engines of growth (Romer, 1990a, 1994b; Grossman and Helpman, 1991; Aghion and Howitt, 1998; Hidalgo and Hausmann, 2009). Analysts sympathetic to Solow's ideas have theorised: 'technology [as] a so-called "public good" and catch up and convergence in the global economy [as] relatively automatic' (Fagerberg *et al.*, 2010: 2).

Originating from this endogenous perspective, spill-overs derived from technology have an important place in economic theory as important drivers of endogenous growth models owing to forces such as knowledge generation and a country's ability to absorb new technologies (Lall, 1992) and also in the development of "absorptive capacity" in order to deliver growth (Cohen and Levinthal, 1990). Cohen and Levinthal (1989) introduced the term "firm absorptive capacity" and pointed out the dual role of R&D as both a producer of new information and a tool to strengthen a firm's learning capabilities.

According to Cohen and Levinthal (1990: 128), the term 'absorptive capacity' is the 'ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends'. Two key factors that facilitate absorption are: 'education and business infrastructure' (Varblane *et al.*, 2012: 41). Cassiman and Veugelers (2002) distinguished between incoming spill-overs, which affect a firm's innovation rate and "appropriability", which affects a firm's ability to assume returns from innovation. In a study of SMEs in the Mexican machining industry, which is a 'low-tech and mature sector', de Fuentes and Dutrénit (2013: 23-24) found that it is less burdensome: 'for SMEs with higher levels of absorptive capacities to reap the benefits from large firms' knowledge spill-overs'.

A theoretical branch of enquiry focuses on the study indigenous innovative capacities expressed as R&D derived from the adoption of new technologies, technology transfer, the training of human resources to manage new technologies and the acquisition of fixed assets. This new transfer of capabilities must take into account international markets and IP transactions that enhance the importance of innovation for economies or companies in the catch-up phase (Gómez and Mitchell, 2014; Valdiviezo, 2012; Fagerberg and Srholec, 2008; Kim, 1997; Nelson, 1993). International transfers of technology through exports and imports but also via Foreign Direct Investment (FDI) are important sources of growth (Görg and Greenaway, 2004; Grossman and Helpman, 1991; Kokko, 1994).

Concerning markets and internationalisation, Lynskey (2004) and Marques de Mello et al. (2010) point out that in contemporary societies characterised by intense levels of globalisation and internationalisation, networks, as well as the use and appropriation of IP rights are valuable resources to promote and adopt innovations. Yet, SMEs face difficulties enlisting 'in supply networks [such as publicly funded research bodies] that allow a gradual [technological] upgrading' (De Fuentes and Dutrénit, 2013: 25). Vázquez (1999), Yam et al. (2011), and Fernández (2013) associate actors in regional innovation systems and innovation culture with an area or territory, which according to the authors, are key determinants of the innovation process. For Lall (1992) and Sanguinetti (2005), innovation activities are greater if companies are in contact with sophisticated, dynamic, and international markets rather than traditional and local markets.

Furthermore, according to Crépon et al. (1998), a firm's innovation processes result from the propensity to innovate, ensure outlay dedicated to innovation and the outcomes of innovation, i.e. property in the form of patents or registrations. Mohnen et al. (2006) examined these issues in six European countries; Benavente (2006) focused on Chile, Sanguinetti (2005) on Argentina while Romo and Hill de Titto (2006) and de Fuentes and Dutrénit (2013) on Mexico. Becheikh et al. (2006) and Shan and Jolly (2013) conducted similar studies with a particular focus on specific industrial sectors in selected regions. According to Cohen (1995), patents are crucial in chemical and pharmaceutical industries while their significance is lower in metal producing industries and in food processing.

Raffo et al. (2008) carried out international comparisons between developed (predominantly European) and three developing economies in Latin America (Argentina, Brazil and Mexico). On Colombia, Langebaek and Vásquez (2007) noted that there does not exist a consensus on the determinants of innovation since specific factors distinguish firms namely, company size, degree of rivalry between companies, the economic sector which the firms belongs to, degree of internationalisation, macro-economic factors, worker and manager skills, market orientation (domestic or foreign), quality of corporate governance and effectiveness of knowledge management.

Furthermore, there is a link between a firm's ability to absorb external information and spill-overs. Innovation is increasingly related to a firm's ability to absorb external information, knowledge, and technology (Segarra and Arauzo, 2008). Determinants of successful innovation depend on the development and integration of new knowledge into the innovation process, with part of this knowledge reaching the firm from external sources (Cassiman and Veugelers, 2002). Industrial innovations can originate from three major sources: in-house R&D, transfers from foreign and domestic agencies and spill-overs from industry agents (customers, suppliers, competitors) and non-industry agents (technological research institutes, universities, public and private research bodies). In-house R&D refers to internal efforts to develop new products and processes. In the Mexican machining industry, SMEs do not significantly rely on R&D for their innovative processes but rather on developing projects with clients, training, and acquisition of equipment to produce new products' (de Fuentes and Dutrénit, 2013: 25).

Lichtenthaler (2008) stated that intensity of innovation often determines the type of innovation activities carried out by companies in that industry. Therefore, there tends to be a positive correlation between innovation and staff expenses on one hand, and the R&D sector in which they operate on the other. Thus, emerging sectors of the economy and rapidly expanding companies often choose to use external sources of innovation (Laursen and Salter, 2006) while in more mature and slow growth sectors, internal sources are usually relied upon (Gooroochurn and Hanley, 2007).

Several empirical studies have examined the possible spill-over effects of foreign firms since the publication of Caves' (1974) work on the Australian case which reveals positive spill-over impacts of FDI on domestic firms. A number of other scholars have examined the issue in different countries including Globerman (1979) on Canada; Blomstrom (1986), Blomstrom and Pearson (1983), and Haddad and Harrison (1993) on Morocco. Such studies confirmed the existence of positive spill-overs from FDI. Foreign ownership of local firms in the Malaysian manufacturing sector, for instance, is generally regarded as fostering innovation activities vis-à-vis wholly nationalised firms (Narayanan and Lai, 2000: 451).

Aitken and Harrison (1999) however, noted a negative impact of FDI on domestic enterprises in Venezuela and the present study reignited interest in this topic. Recent studies have observed negative impacts of FDI on domestic enterprises as discussed by Djankov and Hoekman (2000) who studied the Czech Republic and Kathuria (2000) who examined the Indian case study. In the case of China, conflicting results have been reported. A number of studies found positive spill-overs from FDI (Buckley *et al.*, 2002; Chuang and Hsu, 2004; Liu and Wang, 2003; Tian and Li, 2007) while others (Hu and Jefferson, 2002; Hu *et al.*, 2005) found negative spill-over effects.

Most studies analysed interactions between external sources of knowledge and in-house R&D activities, arguing that the external acquisition of knowledge may stimulate rather than substitute for a firm's own R&D (Arora and Gambardella, 1990; Veugelers, 1997). Cohen and Levinthal (1989a; 1990b) explained the complementarity at some depth using the concept of absorptive capacity as a variable to explain the effect of structural characteristics of an industry on the firm's R&D intensity i.e. conditions of appropriability and technological opportunity. Cohen and Levinthal (1989) concluded that in-house R&D activities not only contribute to the generation of new knowledge but also enhance the firm's ability to assimilate and exploit knowledge generated outside the firm. In other words, they increase the firm's absorptive capacity.

Several researchers have analysed the effects of absorptive capacity and R&D intensity on product innovation, providing empirical evidence to support the positive correlation between these variables (Becker and Peters, 2000; Nieto and Quevedo, 2005). The underlying idea is that the innovative performance of the firm depends on external factors and on the organisation's internal competences (Cornejo, 2010).

According to Vega-Jurado et al. (2008), a firm's technological competences, derived from in-house R&D, are the main determinants of product innovation. The R&D has a direct and positive effect on innovation output insofar as a greater effort in terms of in-house R&D activity increases the organisation's ability to generate new knowledge so as to develop novel or improved products. The R&D has also an indirect effect on increased absorptive capacity, which makes it easier for the firm to exploit externally available knowledge.

The current study also analysed the relationship between R&D activities and technology acquisition on the one hand and product innovation in the industrial sector on the other, focusing on firm size and technological level. We choose these dimensions because several studies have found that both firm size and technological level affect product innovation capacities of firms (Bhattacharya and Bloch, 2004).

4. Methodology

The field of innovation is very complex and hence, there are various approaches to study the determinants of innovation. This section presents data and methodology used to analyse the results of several consecutive Colombian Innovation Surveys (CIS) to obtain insights into the determinants of innovation of manufacturing firms in the country.

4.1 Statistical Model

The knowledge production function approach inspired by the seminal paper of Crépon et al. (1998) was in turn, inspired by Griliches (1979) and is an important theoretical starting point for the present research. Yet, unlike Crépon et al. (1998), this article does not consider the relationship between innovation and productivity but rather, the relationship between knowledge inputs and outputs. There is a field of theoretical inquiry that has considered input-output relationships such as the equation proposed by Conte and Vivarelly (2005) to study the performance of Italian firms; Sun and Du (2010) looked at the Chinese case, Goedhuys and Veugelers (2008) examined the Brazilian economy, Buesa et al. (2002), Segarra et al. (2008), and Benito-Hernandéz et al. (2012) studied the Spanish case, and Meriküll et al. (2012) focused on the Baltic countries.

This study also adapted Conte and Vivarelly's (2005) equation to the

Colombian environment. The introduction of product innovation in the industrial firm is envisaged as a Probit model. According to Wooldridge (2003), the Probit model can be formulated as:

$$P(y_i = 1|X_i) = \Phi(X_i\beta_i) \tag{1}$$

where $y_i = 1$ indicates the firm *i* has introduced a product innovation. X_i is a row vector of the explanatory variables described in equation 2, and is the standard normal cumulative distributive function.

can be expressed in terms of a function *G(z)* that takes values in the interval [0, 1] for all the real numbers *Z*, as shown in the following equation:

$$P(y_i = 1|X_i) = G(z) = G(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k) = G(\beta_0 + \beta x) \tag{2}$$

The matrix *x* represents independent or explanatory variables (input and control variables) of the model. β is a vector of parameters to be considered. According to Wooldridge (2003), for the function *G*, diverse non-linear forms are set out with the aim of ensuring that values of the probabilities are between 0 and 1. Therefore, *G* represents the logistic function $G(z) = \frac{\exp(z)}{1+\exp(z)}$

In this way, the specificity of the function that assures a Probit model approach is the Logit model, where is specified as an accumulated standard normal distribution function:

$$G(z) = \Phi(z) \equiv \int_{-\infty}^{z} \phi(v)dv \tag{3}$$

where $\phi(z)$ is the normal distribution density function.

Given its non-linear characteristics, the estimation of the parameters for equation 2 is carried out through the estimation of the likelihood probability defining the function of likelihood probability as:

$$L(\theta; Y_1, \ldots, Y_n) = f(Y_1;\theta)f(Y_2;\theta) \ldots f(Y_n;\theta) \tag{4}$$

Where $f(Y_n;\theta)$ is the probability density distribution of the variable Y_n, the estimator of maximum likelihood probability is that which maximises the probability function as a consistent and unbiased estimator when the population model $f(Y_n;\theta)$ is correctly specified. This estimation complies with the specification and characteristic of the dependent variable, which is structured as a binary variable, assigning the values of 1 if it has fulfilled a specific event and 0 if it is unfulfilled.

Equation 5 describes the general specifications above that are adapted to the aggregate empirical tests of this input-output relationship of product innovation as carried out for the purposes of this research:

$$\begin{aligned} INNO_{it} \quad &= \alpha_1 + \beta_1 R\&D_{it} + \beta_2 TA_{it} + \beta_3 CORES_{it} + \beta_4 COCUST_{it} + \beta_5 \mathrm{COMPT}ST_{it} \\ &+ \beta_6 \mathrm{COSUPP}_{it} + \beta_7 GP_{it} + \beta_8 SIZE_{it} + \beta_9 TECH_{ht} + \eta_1 E_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

The dependent variable INNO takes the value of 1 if the firm *i* has designed a new product or improved an existing one in the period *t*, and it takes on the value of 0 if the firm did not. The independent variables describe the inputs, i.e. (i) the resources that an innovative firm dedicates in the following dimensions: investment in R&D and investment in technology acquisition (TA), and (ii) co-operation agreements. There are two kinds of agreements: agreements with non-industry agents, i.e. research institutes (CORES) and agreements linked with market activities and relations with three different industry agents: co-operation with customers (COCUST), co-operation with competitors (COCOMPT), and co-operation with suppliers (COSUPP).

There are additional independent variables: Belonging to a foreign industrial group (GP), meaning that the Colombian company is a subsidiary of a foreign-based company; firm size (SIZE) and level of technological development based on the International Standard Industrial Classification of All Economic Activities (ISIC) (OECD 2011), (TECH), classified as high tech and low tech. Finally, dummy variables (E) that indicate the presence or absence of some categorical effect, derived in this case from the circumstance that data is obtained from five different CIS covering duration of this research.

It is important to point out that over the time frame analysed in this article, the design of the questionnaires of the CIS and the survey size varied from one period to the other. For these reasons, in order to adequately compare the results of the variables in equation 5 over time, we had to run the model in two separate stages. First, we ran the model for the second, third, and fourth CIS (2003-2008). In the second stage, we ran the same model for the fifth and sixth CIS (2009-2012).

4.2 Data

This paper draws from longitudinal primary data gathered from the second, third, fourth, fifth, and sixth CIS, which corresponds to the following periods respectively: 2003-2004; 2005-2006; 2007-2008 2009-2010, and 2011-2012. The design of the CIS follows the Oslo Manual (OECD, 1997a; 2005b) and the conceptual guidelines of the Frascati Manual (OECD 2002), in particular categorising the activities that a company performs in order to innovate, create, adapt and disseminate knowledge.

Statistics on development and technological innovation, which are presented to the public, are the results of a process that began in 1996 with the development of the first CIS. The Colombian National Planning Department (*DNP*)[5] and *Colciencias* conducted the first survey covering a total of 885 Colombian industrial establishments. The second CIS was carried out between 2003 and 2004. Since 2003, the DANE has used the same set of data on industrial firms in the CIS that was also utilised in the Annual Colombian Manufacturing Survey. The second CIS obtained information from 6,172 companies (DANE, 2005). The sample size was thus almost seven times larger than in the first CIS of 1996, adding reliability and robustness to official data on innovations in the Colombian manufacturing sector. Just over half (52.9%) of the 6,172 industrial companies surveyed reported product innovations (DANE, 2005). The third CIS (2005-2006) examined 6,080 industrial companies (DANE, 2010a). Regarding company size, the survey obtained information from 3,934 small businesses (64.7%); 1,529 (25.1%) medium sized firms and 617 (10.1%) large enterprises. Only 386 or 6.3% of the companies surveyed were foreign-owned. Slightly above a quarter (26.23%) of manufacturing firms were classified as having generated product innovations (DANE, 2010b).

The fourth CIS (2007-2008) covered 7,683 companies. On company size, the survey obtained information from small businesses (employing between 10 and 50 people) representing 67.6%; medium sized businesses (employing between 51 and 200 people) representing 22.9%; and large enterprises with more than 200 employees representing 9.5% (DANE, 2011a). Regarding the type of capital ownership, 7,203 firms (93.8%) were nationally-owned and the remaining 480 were foreign companies. On product innovations, the proportion of innovative firms remained almost unchanged compared with the third CIS between 2005 and 2006 at 27.96% (DANE, 2011b).

The fifth CIS (2009-2010) covered 8,643 industrial enterprises (DANE, 2012a). Regarding personnel size, the survey obtained information from 6,113 small companies, 1,802 medium sized companies and 728 large companies. Pertaining to the composition of capital ownership, 8,136 companies were domestic while 507 were foreign. In 2010, beverage processing made the largest investment in STI activities; the category of non-metallic mineral products ranked second. In 2009, 78.9% of the funding for STI activities came from enterprise equity capital while 17.7% from loans provided by private banks. Around 42.37% of companies surveyed reported product innovations (DANE, 2012b).

The sixth CIS (2011-2012) covered 9,137 industrial enterprises (DANE, 2013a). The survey obtained information from 6,482 small companies, 1,893 medium sized companies, and 762 large companies. A total of 8,606 companies were locally owned and 531 (or 5.8%) had foreign ownership. In 2011, the manufacturer of other chemicals reported the highest percentage of personnel involved in the realisation of STI activities with 7.2% of employed persons, followed by manufacturer of coffee with 4.8%. In 2012, the same activities recorded the highest percentages of personnel involved in performing STI activities, that is, the manufacturer of other chemicals with 8.1%, and the manufacturer of coffee with 5.6%. Around 38.27% of industrial companies surveyed reported product innovations (DANE, 2013b).

5. Empirical Results

This section presents and discusses empirical results based on the relationship between R&D and TA on one hand, and product innovation in Colombian industrial firms on the other, focusing first on the aggregate level before examining firm size and finally on estimations by technological level.

5.1 Aggregate Estimations

Aggregate Probit estimates (Tables 4 and 5) show a positive and highly significant relationship between product innovation and both R&D and TA, where the former has a higher probability than the latter over the period 2003-2012. These results do not seem to confirm Gerschenkron's (1962) hypothesis regarding the patterns of economic catch-up by emerging economies.

Table 4: Aggregate estimations; 2003 to 2008 (CIS II, III, IV)

INNO (independent variables)	Coefficient	Marginals
R&D	.0011739** (.000312)	.0004379** (.0001164)
TA	.0005524** (.000143)	.0002061** (.0000534)
CORES	.1939909** (.0427795)	.0742326** (.0167078)
COCUST	.6831103** (.0306182)	.2630628** (.0117305)
COSUPP	.3480927** (.0340664)	.1338634** (.0133502)
COCOMP	.2146666** (.0362606)	0820073** (.0141143)
GP	.2176517** (.0674129)	0837194** (.0265415)
SIZE	.3329825** (.0156032)	.1242301** (.0156032)
TECH	.120496** (.0259906)	.045502** (.0099203)
E3 (Dummy variable)	-100.849** (.0273614)	-.3375051** (.0079155)
E4 (Dummy variable)	-.9997636** (.0258689)	-.3484427** (.008159)
CONSTANT	-.7485381** (.0305352)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2005; 2010a; 2010b; 2011a; 2011b)

Table 5: Aggregate estimations; 2009 to 2012 (CIS V, VI)

INNO	Coefficients	Marginals
R&D	.6487095** (.0429571)	.2543096** (.0162199)
TA	.4839901** (.0386797)	.18536** (.0141979)
CORES	.0506926 (.0569992)	.020017 (.0225649)
COCUST	.4049483** (.0396001)	.1583418** (.01527)
COSUPP	-.031717 (.0393875)	-.0124818 (.0154909)
COCOMP	.0560683 (.0434209)	.0221236 (.0171653)
GP	.1080468 (.1746221)	.042829 (.0695513)
SIZE	.2535691** (.0281678)	.0998435** (.0110955)
TECH	.5012377** (.0782196)	.1975213** (.0297689)
E5 (Dummy variable)	.0137522 (.0382096)	.0054140 (.015040)
CONSTANT	-1.250.138** (.0603174)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2012a; 2012b; 2013a; 2013b)

Spill-overs expressed by co-operation agreements with research institutes (CORES) yielded a positive and highly significant relationship with product innovation for the 2003-2008 period where there was a positive but non-significant relationship during 2009-2012. This finding suggests that the industrial firms analysed established closer research ties with non-industry agents such as research institutes, universities, and technological research centres, generating product innovations during the first period. Nevertheless, this significantly positive trend was not sustained between 2009 and 2012.

Analysis on the relationship between product innovation and co-operation with industry agents (customers, competitors, and suppliers) yielded mixed results. Pertaining to the relationship and cooperation of suppliers (COSUPP), there existed a positive and highly significant relationship during the first period (2003-2008) while a negative and non-significant relationship was noted for the second period (2009-2012). The relationship between product innovation and co-operation with customers (COCUST) is positive and highly significant over both periods. The spill-overs from the firms' co-operation with competitors (COCOMP) yielded highly significant and positive results for the first period only. These results indicated that during the period analysed, Colombian industrial firms created closer positive co-operation with industrial agents.

The spill-overs from firms belonging to a foreign industrial group (GP) yielded highly significant positive results for the first period only but for the second period the positive relationship was inconsistent with the findings by Caves (1974), Globerman (1979), Blomstrom and Pearson (1983), Haddad and Harrison (1993), or Narayanan and Lai (2000).

The aggregate Probit estimates show a positive and highly significant relationship between product innovation and both SIZE and TECH over the period 2003-2012. In accordance with Vega-Jurado et al. (2008), our results suggested that the positive relationship between the inputs R&D and TA and the product innovation output did not depend on firm size or technological level.

5.2 Estimations by Firm Size

As regards the analysis of the independent variable that measures co-operation between industrial firms and research institutes (CORES), it should be noted that there was a negative relationship with CORES for medium and large firms in the second period (2009-2012), while the 2003-2008 period yielded a positive and significant relationship, suggesting closer co-operation during the first period.

The analysis of spill-overs from the co-operation between industrial firms and their customers (COCUST) suggested a positive and highly significant relationship with product innovation during both periods. This result is similar to the findings by de Jong and Vermeulen (2004), which confirmed the importance of market research and the need to examined customers' unmet needs in the generation of new products.

Pertaining to co-operation with competitors (COCOMP), the relationship is positive for all firms independent of size for both periods analysed, which is similar to the results obtained by de Jong and Vermeulen (2004) in the case of small Dutch firms.

As regards co-operation with suppliers (COSUPP), the picture was ambiguous. A positive and highly significant relationship for small, medium, and large firms for the first period was observed, but this trend did not hold for the second period in which the relationship was negative in the case of small firms. This result differed from the findings of Ács and Audretsch (1988) and Fuentes and Dutrénit (2013), who observed that small firms were more innovation-intensive compared with their large counterparts since – for the

Table 6: Estimations by firm size; 2003 to 2008 (CIS II, III, IV).

	SMALL		MEDIUM		LARGE	
INNO	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**
R&D	.0010943 (.0006467)	.0003608 (.0028103)	.0028103** (.0008812)	.0011196** (.0003511)	.0007859 (.0006573)	.0002949 (.0002461)
TA	.0002914 (.000209)	.0000961 (.0000689)	.0010375 (.0003846)	.0004133 (.0001533)	.0009488* (.0004337)	.000356* (0.029)
CORES	.1335123 (.0734353)	.0455979 (.0259096)	.233138* (.0778183)	.0927304* (.0307009)	.3094767* (.098904)	.111367* (.0337546)
COCUST	.7518602** (.0440892)	.2731869** (.0167974)	.618971** (.0557806)	.2423802** (.0209405)	.3987495** (.0887156)	.145458** (.0311719)
COSUPP	.3538186** (.0516016)	.1248536** (.0192248)	.3240685** (.0617057)	.128641** (.0242025)	.3514697** (.0908362)	.1281411** (.0318546)
COCOMP	.2874553** (.0561923)	.1007551** (.0207433)	.1723665** (.0670046)	.0686792** (.0266295)	.0896402 (.0955909)	.033343 (.0352138)
GP	.225761 (.1414959)	.0790799 (.0521826)	.2187057 (.1233874)	.086977 (.0486332)	.2223731 (.1222218)	.0805039 (.04236)
TECH	.1085342** (.0330819)	.0364893** (.0113241)	.0795427 (.0481621)	.0317099 (.0192029)	.2889999** (.0847471)	.104280** (.0291849)
E3 (Dummy variable)	-1.122** (.036021)	-.316459** (.0087266)	-.815903** (.0519223)	-.311120** (.0183505)	-.776268** (.0853999)	-.295613** (.0317071)
E4 (Dummy variable)	-1.152.94** (.0339419)	-.316459** (.0095701)	-.775055** (.0501155)	-.298488** (.0182043)	-.596589** (.0841649)	-.225757** (.0313629)
CONSTANT	-.0039781 (.0281487)	-	.1468274** (.0407397)	-	.3782865** (.0695401)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2005; 2010a; 2010b; 2011a; 2011b)

Table 7: Estimations by firm size; 2009 to 2012 (CIS V, VI).

	SMALL		MEDIUM		LARGE	
INNO	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**
R&D	.6998613** (.0537985)	.2723852** (.0205317)	.4913158** (.0933427)	.1918329** (.0350881)	.654296** (.1181391)	.2279358** (.0384785)
	TA.4882047** (.0456277)	.1789632** (.0159145)	.5441052** (.0869054)	.2137422** (.0329932)	.3406368 (.1246781)	.1280284 (.0477949)
CORES	.11549 (.0763203)	.0444848 (.0297376)	-.1026306 (.1209282)	-.0409256 (.0481842)	-.0266034 (.1322987)	-.0097204 (.0484582)
COCUST	.3972804** (.0478585)	.1502500** (.0178813)	.4222026** (.0878463)	.1670871** (.0342548)	.4372732** (.1240339)	.1604864** (.0454566)
COSUPP	-.0909264 (.0480563)	-.0344258 (.0181136)	.0756548 (.0868831)	.0301443 (.0345926)	.1449877 (.1232507)	.0529453 (.0450389)
COCOMP	.0323429 (.0523426)	.0123257 (.019997)	.0898906 (.0994634)	.035778 (.0395021)	.1817490 (.1336075)	.06499 (.0468088)
GP	-.0702116 (.233971)	-.0263841 (.0868407)	.57304 (.3460687)	.2147941 (.1154307)	.1212704 (.5261233)	. 0430119 (.1810856)
TECH	.4980059** (.1029393)	.1959563** (.0404425)	.5141525** (.1538132)	.1964935** (.0543542)	.548818** (.2389198)	.1743055** (.0629987)
E5 (Dummy variable)	.0023007 (.0461324)	.0008745 (.0175314)	.0890743 (.0832803)	. 0 3 5 4 7 6 0 (.0331237)	-.040185 (.1229133)	-.0147016 (.0451342)
CONSTANT	-.9737948** (.0519547)	-	-.8171601** (.0867945)	-	-.4933361** (.1275334)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2012a; 2012b; 2013a; 2013b) most part – small firms faced 'fewer rigidities to hinder the introduction of the innovation' (Vega-Jurado, *et al.*, 2008, 617).

As regards the relationship between being either high-tech or low-tech and product innovation, there was a positive and significant, or highly significant relationship for all firms over both periods with the sole exception of medium sized firms during the 2003-2008 period showing a positive, albeit non-significant, relationship. These results were consistent with the findings of Bhattacharya and Bloch (2004).

5.3 Estimations by Technological Level

Pertaining to estimations of being either low-tech or high-tech and the corresponding input-output relationship between R&D and product innovation, the relationship is positive for both low-tech and high-tech levels during the periods analysed. This was consistent with the results of Arvantis and Hollenstein (1994), Becker and Peters (2000), and Vega-Jurado et al. (2008). The same held true for the relationship between the input variable TA and product innovation for low-tech and high-tech firms over both periods.

Pertaining to the analysis of independent variables that measured co-operation between industrial firms and research institutes (CORES), the study noted a very mixed picture with the only positive and highly significant relationship existing for low-tech firms in the 2003-2008 study period. Moreover, there existed a positive and highly significant relationship between product innovation and the co-operation of low-tech and high-tech firms with their customers (COCUST) during both periods, with the exception of high-tech firms in the latter period. The findings appeared to support de Fuentes and Dutrénit (2013:25) discoveries on SMEs in the Mexican machining industry regarding the importance of: 'developing projects with clients'.

On the co-operation with competitors (COCOMP), the relationship was positive for all the firms for both periods. Yet, only the first period (2003-2008) yielded significant results. Regarding co-operation with suppliers (COSUPP), the picture was mixed. There existed a positive and highly significant relationship for low-tech and high-tech firms for the first period though this trend did not hold for the second period in which both results turned out negative and non-significant.

The relationship between the independent variable belonging to a foreign industrial group (GP) and product innovation was positive for low-tech and high-tech firms during both periods, with a statistically significant relationship for the low-tech level during the 2003-2008 period. Our results confirmed the tendency of so-called 'latecomers' or emerging economies in the aspirational, catch-up phase to follow and imitate technological trends as well as rely on inward capital rather than driving product innovation (Gerschenkron, 1962).

Table 8: Estimations by technological levels; 2003 to 2008 (CIS II, III, IV).

	HIGH TECH		LOW TECH	
INNO	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**
R&D	.0012697 (.0007119)	.0004953 (.0002779)	.001138* (.0005667)	.0004184* (.0002085)
TA	.0003383 (.0003233)	.000132 (.0001262)	.0006282* .0001986	.000231* (.0000731)
CORES	.1371940 (.0947058)	.0540201 (.037562)	.2090324** (.0553282)	.0792624** (.0215116)
COCUST	.702061** (.0689927)	.2740114** (.0260854)	.6787481** (.036617)	.259914** (.0140832)
COSUPP	.4096764** (.078335)	.1616521** (.0308236)	.3325234** .0413402	.1265353** (.0161193)
COCOMP	.2377311* (.0846914)	.093811* (.0336291)	.2071989** (.0451116)	.0782165** (.017413)
GP	.2726801 (.142956)	.1080388 (.0569209)	.1816044* (.090951)	.0688069* (.0353291)
SIZE	.3776659** (.0375237)	.1473434** (.0146587)	.3234972** (.0176237)	.1189452** (.0064928)
E3 (Dummy variable)	-1.046.165** (.0641686)	-.3733386** (.0201552)	-.9999576** (.0313555)	-.3282224** (.0089887)
E4 (Dummy variable)	-.9885253** (.0610917)	-.3633029** (.0206272)	-1.003.897** (.0296689)	-.3442503** (.0093497)
CONSTANT	-.3636793** (.0694584)	-	-.39455** (.0340137)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2005; 2010a; 2010b; 2011a; 2011b)

Table 9: Estimations by technological levels; 2009 to 2012 (CIS V, VI).

	HIGH TECH		LOW TECH	
INNO	**Coefficients**	**Marginals**	**Coefficients**	**Marginals**
R&D	.4753492* (.1634115)	.1676269* (.0550164)	.6620265** (.0448781)	.259348** (.0169865)
TA	.4976805* (.1596899)	.1852943* (.0596506)	.4858427** (.0395496)	.1843355** (.0143407)
CORES	-.2735031 (.2396122)	-.1031669 (.092719)	.0715042 (.0591735)	.0281188 (.0233683)
COCUST	.2597174 (.162519)	.0947794 (.0590761)	.4109674** (.041024)	.159707** (.0157139)
COSUPP	-.0184997 (.1701757)	-.0067575 (.0622184)	-.032546 (.0407604)	-.012730 (.0159302)
COCOMP	.0160274 (.1792402)	.0058414 (.0652353)	.0590607 (.044837)	.0231786 (.0176397)
GP	.169451 (.6767221)	.0594842 (.2273221)	.1196435 (.1822813)	.0472569 (.0724919)
SIZE	.2436736* (.1157034)	.0889296* (.0422346)	.2531444** (.0290842)	.0990744** (.0113899)
E5 (Dummy variable)	-.1662835 (.1616133)	-.0604716 (.0584739)	.0228035 (.03933)	.008922 (.0153800)
CONSTANT	-.4613649* (.2545261)	-	-1.265.156** (.0621729)	-

Robust standard errors in parentheses. *significant at 5%; **significant at 1%. Source: Authors' calculations; DANE (2012a; 2012b; 2013a; 2013b

6. Concluding Remarks

This paper discussed the relationship between product innovations of industrial firms in Colombia vis-à-vis their formal R&D activities and TA between 2003 and 2012. This relationship was also discussed by comparing SMEs with large firms (LFs), and between firms that are low-tech (LT) or high-tech (HT). Firm size and LT or HT level turned out to be important discriminating factors for innovation outcomes at the firm level. In particular, our analysis indicated that SMEs and LFs from both LT and HT levels relied more on R&D than on TA.

In summary, product innovation among industrial enterprises in Colombia tended to be intra-organisational in nature and depended on the characteristics, resources and capabilities that enabled firms to activate their innovative abilities. Therefore, the results showed a positive impact on the probability of introducing product innovation in relationship with R&D and TA. While the theory on the association between R&D and TA with product innovation showed a positive and direct relationship, the results of the present research only partially coincided with this statement on innovation theory.

Variables measuring the impact of co-operation with industry agents such as customers, suppliers and competitors, and research institutes focusing on product innovation were studied. We analysed the only form of co-operation that was highly significant and positive for all firms and at both LT and HT levels. Hence, we emphasised that the stronger the co-operation with customers, the higher the probability of achieving product innovation. However, we cannot make such claims for other forms of co-operation.

It should be noted that the analysis considered Colombian industry in its entirety rather than dividing the country's industrial sector into a number of subsectors. Each one of those subsectors followed different trends and performance styles with respect to innovation. Moreover, each industrial subsector varied in terms of its composition of labour and capital in the production process as a consequence of innovation activities, R&D and technology transfer as well as different financial and technical resources. The aforementioned serves as an invitation for future studies that focus on specific subsectors within Colombian industry to analyse the strengths and weaknesses of individual subsectors pertaining to their innovation performance.

It is important to highlight that the reflections would be particularly useful and purposeful provided that policy strategies (public and private) for the industries in Colombia had been formulated. The results of the econometrical models led the present research to formulate different strategies that consider size as well as technological development of the industrial firms. For instance, LFs tended to have more financial muscle and medium and small sized firms should benefit from financial support provided by the government. Besides, LFs tended to almost always receive support from their headquarters, which in most cases are located outside Colombia, while the small and medium firms required some degree of support in order to, for example, strengthen their capacities to cooperate and share costs. Similarly with other Latin American economies, Colombia has undergone a process of deindustrialisation and a resultant 'decline in innovation capacity' over recent years as pointed out by Rodrik (2015). Consequently, Colombia needs to rethink its current industrial policies.

The findings pertaining to a subsidiary or a part of foreign industrial group (GP) suggested a positive relationship between product innovation and being a medium or large firm. Yet, we cannot make the same claim in the case of small enterprises. Similarly, belonging to a foreign industrial group (GP) and being either an LT or an HT firm suggested that the probability of achieving product innovation is positive. Several differences arise in the input-output relationship with respect to a firm's size. On the aggregate level and at the LT or HT levels, the size of the firm proved to be a remarkably positive and significant indicator for product innovation.

Despite this research showing a positive relationship between R&D and TA, there is a need for a different theoretical vision of a non-linear model of the relationship between innovation, scientific research and R&D as well as TA such as is offered by paradigms inspired by open innovation approaches. These perspectives consider 'that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology' (Chesbrough, 2006: xxiv). In other words, not thinking about innovation as determined by R&D and TA encourages the discussion on why enterprises with similar systems and effort intensity in R&D and in TA obtain different product innovation results.

This is important because from a linear perspective, public policies that foster product innovation such as subsidies or tax relief, for example, and most of the business strategies for such innovation are usually based on correcting the deficit of this innovation by increasing the R&D or TA budgets. Therefore, these policies have benefited agents that can be considered closest to the idea of research and innovation (enterprises, technological research centres, laboratories, universities), but the expected results have not made themselves evident. From a non-linear viewpoint, innovation-fostering policies and objectives can be oriented towards the creation of favourable political, sociocultural and organisational environments by emphasising knowledge appropriation, generation and use as well as information and communications technologies (ICT) in the productive processes, which in recent studies, showed more favourable results for the stimulation of business innovation (Cornejo, 2010).

From this non-linear standpoint of R&D or TA on product innovation, society as a whole can be open to new research and innovation knowledge, standards, and values in a broader sense, knowing with certainty that all the institutions and organisations can jointly help enterprises be more innovative, and therefore, more sustainably and integrally competitive. Thus, from the perspective of a non-linear innovation approach, policies that foster innovation must recognise that innovations are a complex and interactive process that is influenced by an enterprise's diverse internal and external variables. Moreover, science, technology and innovation play a predominant role in the long-term social and economic development of countries. The important role of government and local authorities in addressing market failures and in promoting an environment of knowledge generation, dynamic entrepreneurship and business innovation cannot be underestimated (Gómez and Mitchell, 2014: 57).

It is necessary to highlight the study's implications for academics, managers, and decision-makers who have responsibilities for or interests in the subject of innovation. Indeed, findings contribute to a better understanding of what the determinants of innovation are and what the impact of innovation is on the set of performance measures. This could be used to rethink current organisational structures and institutional scope of the Colombian National Innovation System (CNIS), as well as aid the design and implementation of a more adequate National Innovation Systems (NIS) with similar characteristics around the world. Sharpening the focus on the collaborative integral parts of a future CNIS is important. This does not only include product innovation via co-operation with customers, suppliers, and competitors, but also taking a more global and macro view of the product innovation process, including its social and cultural dimensions.

Naturally, the present research has important limitations that should be addressed in future studies. We could, for instance, obtain a clearer picture of the product innovation activities of industrial firms by including a variable that takes account of the regional location of a firm within the territory of Colombia. Throughout its history, this Andean country has been held back by poor transport links between its industrial centres and ports. Furthermore, Colombia has only recently begun a major infrastructure-upgrading programme including data on location that could sharpen the analytical efforts of future research. It should be stressed that the study focused exclusively on product innovation in one specific industrial sector.

Hence, future studies may benefit from an understanding of innovation drivers by considering the services sector, for example, and by carrying out comparisons across various sectors. Prospective research could also take into consideration the full range of determinants of innovation by including process and market innovations. The measurement approach was rather basic, i.e. the researcher relied on dichotomous questions. Despite removing bias and adding efficiency, the author missed some of the complexity and depth involved in the operation of firms carrying out innovation processes. Finally, enriching the methodological approach by including qualitative methodologies such as interviews would enable a clearer picture of how fruitful the introduction of product innovation has actually been.

The results show that a strategy to promote innovation in medium sized industrialised economies like Colombia should come hand in hand with the emphasis on R&D activities generally. Improvement of this activity in any society implies sophisticated strategies that strengthen educational capabilities in firms and in educational systems that would enable the recruitment of suitable resources and utilisation of human capital to advance the results of product innovation within the industrial sector; this will provide the industries a competitive edge. This strategy also demands strong social networks and co-operation between firms, universities, technical institutes, and governments. The Quintuple Helix Model (Carayannis *et al.*, 2012) is a good and relevant fit to meet the challenges of a globalised environment in which countries focus on sustainability embedded in relevant social environments such as political, educational, economic, natural, and media-based cultural systems.

The present trade and industry trends in a globalised economy call for a strengthening of the sources of product innovation, promoting interactions of national and international firms and generating strong spill-overs of co-operation inside the value chains. Open innovation rather than the "traditional" innovation system with heavy state involvement seems to be the prevailing policy trend. A necessary requirement for this would be to measure the impact of Colombian state agencies on the CNIS that would help public policy-makers and industrial firms to consolidate strategies that buttress the performance of Colombian industrial firms.

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Notes

1. Departamento Administrativo Nacional de Estadística – DANE.
2. The survey is known in Colombia as 'Encuesta Nacional de Innovación y Desarrollo Tecnológico – Industria Manufacturera (EDIT)' (National Survey of Innovation and Technological Development – Manufacturing).

[3] Departamento Administrativo de Ciencia, Tecnología e Innovación (Colciencias) (Administrative Department of Science, Technology and Innovation).

[4] CONPES is the Spanish acronym for Consejo Nacional de Política Económica y Social (National Board of Economic and Social Policy). This Colombian governmental institution elaborates and publishes the Documentos CONPES.

[5] Departamento Nacional de Planeación – DNP .

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