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A comparative analysis of the innovation performance between foreign subsidiaries and owned domestic firms in Colombian manufacturing sector

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Un análisis comparado del desempeño innovador de las empresas extranjeras y nacionales en la industria manufacturera de Colombia
Uma análise comparativa do desempenho inovador das empresas nacionais e estrangeiras na indústria manufatureiras da Colômbia

AUTHORS

Nadia Albis
Instituto Complutense de Estudios Internacionales (ICEI), Spain
Observatorio Colombiano de Ciencia y Tecnología (OCyT). Colombia
nalbis@ocyt.org.co

Isabel Álvarez[1]
Instituto Complutense de Estudios Internacionales (ICEI), Spain
mialvare@ucm.es

1. Corresponding author: Instituto Complutense de Estudios Internacionales (ICEI), Universidad Complutense de Madrid; Finca Mas Ferré, Edificio A; Campus de Somosaguas; 28223 Pozuelo de Alarcón (Madrid); SPAIN.

This paper analyzes the innovation performance of foreign subsidiaries compared to domestic owned firms using a firm level dataset of Colombian manufacturing firms. The results show that foreign subsidiaries are superior in knowledge production over domestic firms and this superiority is because they make a more intensive use of internal and external knowledge inputs. However, when foreign subsidiaries are compared with national exporting companies the gaps in innovation performance is not as wide. Our findings can be seen as a new contribution that hightlights how the links between innovation and firm's internationalization define a relevant relationship, important also for developing contexts.

Este trabajo analiza el desempeño innovador de las subsidiarias extranjeras en comparación con las empresas nacionales usando datos a nivel de firma para la industria manufacturera. Los resultados evidencian que las subsidiarias extranjeras son superiores en la producción de conocimiento en comparación con las firmas domésticas, explicado por una mayor intensidad en el uso de insumos internos y externos de conocimiento. Sin embargo, cuando las subsidiarias extranjeras se comparan con las firmas domésticas que exportan, la brecha en el desempeño innovador no es tan amplia. Los resultados contribuyen a dilucidar como los vínculos entre innovación e internacionalización de las firmas son relevantes también en países en desarrollo.

Este artigo analisa o desempenho das subsidiárias estrangeiras em comparação às firmas de propriedade nacional no que tange à inovação, utilizando um dataset ao nível da firma para as empresas manufatureiras colombianas. Os resultados mostram que as subsidiárias estrangeiras apresentam um melhor desempenho na produção de conhecimento do que as empresas nacionais e tal superioridade se deve ao uso mais intensivo de insumos de conhecimento interno e externo. Entretanto, quando as subsidiárias estrangeiras são comparadas às companhias exportadoras nacionais, a diferença do desempenho entre tais empresas não é muito significativo. Estes resultados podem ser considerados uma nova contribuição, que destaca como a combinação entre a inovação e a internacionalização da firma define uma relação relevante e, do mesmo modo, importante para contextos em desenvolvimento.

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1. Introduction

The positive behavior of flows of foreign direct investment (FDI) in recent decades has been accompanied by a substantial increase in the participation of developing countries, mainly Asian and transition economies, but also, to a lesser extent, Latin American and Caribbean countries. Although the innovation activities of multinational enterprises (MNE) still show a high concentration into the developed home countries, since the mid-1990s there has been an expansion into developing countries as well (UNCTAD, 2005; Laurens et al., 2015).

The traditional literature about the effects of foreign direct investment is based on the assumptions of a technological superiority of the foreign subsidiaries over their domestic counterparts (Blomström & Kokko, 1998). This superiority is revealed in the productive advantages of MNE and in the superior innovation capacity of foreign subsidiaries (Bellak, 2004; Castellani & Zanfei, 2007; Criscuolo et al., 2010; Silva et al., 2013; Siedschlag & Zhang, 2015). Empirical studies in more developed countries generally support the hypothesis of the technological superiority of foreign subsidiaries, while the evidence from developing countries tends to be more heterogeneous. In Colombia, the most relevant contributions about the innovation behavior of foreign firms include foreign ownership as a control variable to explain innovation in manufacturing industry, e.g. Langebaek & Escobar (2007), Arbeláez & Parra (2010) and Gallego et al. (2015).

In this paper we analyze the innovation performance of foreign subsidiaries in Colombia compared to their domestic counterparts and the factors that could explain the differences in innovation capacities. Our hypothesis is that subsidiaries are superior in the knowledge production (innovations) over domestic firms and this superiority is because they make a more intensive use of internal and external knowledge inputs. For this purpose, we use a structural model that compares the technological differences between foreign subsidiaries and national firms, which is organized through three analytical blocks: (i) the decision to invest in innovation activities; (ii) the firm efforts made in these investments and (iii) innovation outputs.

The results validate our hypothesis about technological superiority of foreign subsidiaries over domestic firms; in particular, in relation to the intensity in the use of innovation inputs and outputs with a greater degree of novelty and patenting. However, we find that is low the technological gap between foreign subsidiaries and national exporting firms. In comparison with the previous evidence from more developed countries, there are similarities but also differences in the factors that determine the innovation capacity of subsidiaries; particularly, the type and the intensity of the innovation activities.

The following section presents the conceptual framework and the development of our hypothesis. In the third section, we describe the methodology and the data source. In the fourth section we show and discuss the results obtained. In the fifth section we present some concluding remarks.

Key words
Innovation, internationalization, subsidiaries, multinationals, Colombia, manufacturing industry

Palabras clave
Innovación; internacionalización, subsidiarias; multinacionales; Colombia; industria manufacturera

Palavras chave
Inovação, internacionalização, subsidiárias, multinacionais, Colômbia, indústria manufatureira

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F23, O31, D22

2. Theoretical and empirical background

Several studies have attempted to explain the relationship between firms' internationalization through FDI and innovation capabilities. Although a traditional motivation of R&D investment in subsidiary firms is the need to adapt products and processes to host markets (Mansfield et al., 1979), the growth in FDI and the strong dynamic of technological change in the last thirty years, have generated modifications in multinational business strategies, aimed at a higher diversification of their technological competencies to absorb and combine geographically disperse knowledge and capacities. The fact is that MNE have evolved toward greater integration through international networks and less hierarchical corporate structures, in which subsidiaries acquire a more active role in innovation activities (Hedlund, 1994; Cantwell, 1995; Iammarino & McCann, 2013). The multinational are also increasingly more active in establishing technological alliances with foreign companies and organizations to develop new technologies (Reddy, 2005; Castellani & Zanfei, 2007).

But not all subsidiaries develop the same technological and innovation capacities abroad. This depends on global multinationals strategies, the own evolution of the subsidiaries in time, the specific localization advantages and the sectorial technological opportunities (Birkinshaw & Hood, 1998; Balcet & Evangelista, 2005; Cantwell & Mudambi, 2005; Dunning & Lundan, 2009). In fact, the literature distinguishes two types of subsidiaries according to their technological responsibilities within a multinational group (Kuemmerle, 1999; Cantwell & Mudambi, 2005): (i) competence exploiting subsidiaries, and (ii) competence creating subsidiaries. In the former, innovation activities are generally directed toward adapting products and processes to local markets, while the latter seek the creation or acquisition of new or complementary technological competencies that increase the knowledge stock and innovation capacity of the MNE, for both local and global markets. Knowledge generation activities of the adaptive type are generally more common in subsidiaries located in developing countries (Kuemmerle, 1999), where is possible to find subsidiaries that do not undertake any technological activities or with lesser innovation impacts, as for example the investment in incorporated technology (Marin & Bell, 2010).

Concerning the relationship between innovation and firms' internationalization, a first point of reference is the empirical evidence about the superior productivity levels of multinationals and exporting firms, compared to non-exporter domestic firms (e.g. Doms & Jensen, 1998; Helpman et al., 2004)[2]. According to this literature, multinationals and exporting firms possess productivity advantages that allows them to compete under better conditions in external markets and could explain the technological gap observed between them and non internationalized firms (Bellak, 2004).

A more recently literature, has gone beyond productivity and include explicit measures of innovation inputs and outputs to assess the innovation performance of subsidiaries. In these works the differences in productivity between subsidiaries (whether national or foreign) and domestic firms is explained by the differences in knowledge production and the greater learning capacity of subsidiaries, because of their global engagement (Castellani & Zanfei, 2007; Criscuolo et al., 2010). The greater integration of subsidiaries in the multinational group, confers to them more innovation potential because each unit of the group learns from the environment in which it operates and transmits that knowledge within the corporation (Frenz & Ietto-Gillies, 2007). The evidence in fact shows that the degree of integration of subsidiaries within their multinational group is one of the main determinants of their superior innovation behavior in developing countries (Marin & Bell, 2010).

There are two main approches to assess the innovation performance of subsidiaries. The first one focuses on the identification of patterns of innovation strategies in subsidiaries, without taking into account the comparison with local firms (e.g. Bas & Sierra, 2002; Cantwell & Mudambi, 2005; Marin & Bell, 2010). The second one refers to the contributions that include the type of firm (i.e. foreign or domestic) as explanatories variables in models of the determinant actros of innovative behavior, comparing the level and significance of their estimated effects (e.g. Sadowski & Sadowski-Rasters, 2006; Frenz & Ietto-Gillies, 2007; Criscuolo et al., 2010). Follwing this line, we find a group of contributions that use the Crépon, Duguet and Mairesse model (1998, henceforth CDM), to assess the innovation performance of foreign subsidiaries, which permimts the correction of endogeneity problems in the estimation of the determinants of innovation and the sample selection biases that characterize the data from innovation surveys (e.g. Dachs et al., 2008; Masso et al., 2012). In addition, some works have used other techniques to identify those factors that better explain the differences in knowledge production between foreign and domestic firms: (i) the propensity score matching method, a technique that allows the comparison of innovative differences between a target group (i.e. subsidiaries) and a control group (i.e. domestic firms) (Falk, 2008); and (ii) the innovation accounting technique, proposed by Mairesse & Mohnen (2002), that allows to explaining the differences between innovation outputs according to firms types and the contribution of multinationality to innovation (Criscuolo et al., 2010).

The empirical evidence about technological superiority of foreign subsidiaries is mixed, in both developed and developing economies. In Scotland, it has been found that foreign ownership has a positive impact on the probability of achieving product innovations in manufacturing industry (Love et al., 1996). In a similar way for United Kingdom, Frenz & Ietto-Gilles (2007) found that the greater propensity to invest on innovation activities in foreign subsidiaries occurs when they undertake innovation activities on an ongoing basis.

In Nordic countries, Dachs et al. (2008) find that there is no difference in the propensity and intensity to undertake R&D, but the subsidiaries produce more innovations and have higher levels of cooperation with other organizations in the national system of innovation. In contrast, foreign subsidiaries in Estonia have more intensive investment in innovation activities but lower capacity to produce innovation outputs (Masso et al., 2012). Sadowsky & Sadowsky-Rasters (2006) found that foreign subsidiaries in the Netherlands are more innovative than domestic firms, although predominate imitative innovations (new for the firm) over "radical" innovations (new for the international market). For United Kingdom, Criscuolo et al. (2010) obtained that firms with global engagement (multinationals and exporters) innovate more than domestic firms, which is due to their intensive use of knowledge inputs (R&D) and to their greater capacity for learning from global and local knowledge networks. Moreover, the relative importance of each knowledge source in subsidiaries varies with the type of innovation, whether patent or technological innovation. Castellani & Zanfei (2007) had similar findings for the case of Italy, as did Wagner (2006) for Germany, Silva (2013) for Portugal and Siedschlag & Zhang (2015) for Ireland. Empirical evidence with a panel of manufacturing Spanish firms confirm that exporting firms tend to introduce more product innovations and get more patents (Salomon & Shaver, 2005), and Casillas et al. (2015) found that different forms of knowledge and learning interact to shape the pace of internationalization for a small sample of firms in Spain, in addition to the expected direct effects of learning.

For Latin America countries, there have few studies about subsidiaries innovation performance or the impact of foreign ownership on innovation. According to Alvarez (2001), in Chile, exporting is more significant than foreign ownership in explaining innovation performance. They also find that foreign ownership is not associated with more R&D and with technological innovations (product and process), but foreign investment affects the probability of introducing marketing and design innovations. Alvarez

& Robertson (2004) had similar findings for Mexico: while exporting affects most of the innovation measurements, foreign ownership only affects process innovations and the acquisition of licenses. For the same country, Brown & Guzmán (2014) found that foreign investment affect the propensity to innovate and the innovation effort as well as the generation of product and process innovations. Also Araújo et al. (2015) show the existence of learning by exporting effects in the case of Brazilian manufacturing firms in the period 2006-2008.

In a set of interrelated works for Latin America countries, that used the CDM model (Crepon et al., 1998), it has been found that efforts in innovation are weakly related to foreign ownership. In the cases of Argentina, Chudnovski et al. (2006) showed that foreign ownership is not associated to the propensity to do innovations activities, innovation investment intensity and innovation outputs. Arza & López (2010) confirm this result, although the effect of foreign ownership is positive and significant in the case of process innovation. Minority foreign ownership in Uruguay does not increase the propensity to undertake innovation activities and their effect on the innovation intensity is negative (Cassoni & Ramada, 2010). For Peru, Tello (2015) found that foreign firms show a higher probability of producing non-technical innovation only in high-tech sectors, but do not found a significant impact in technical innovation (i.e product and process). Finally, Arbeláez & Parra (2011) found that the presence of foreign capital in Colombia does not affect the probability that a firm engages in R&D, but is associated with greater spending on innovation and a greater probability of obtaining radical innovations. For the same country, a similar result is found for Gallego et al. (2015).

Given this literature, review two interrelated hypotheses are proposed here. The theoretical predictions and the available empirical evidence indicate that the technological superiority of foreign subsidiaries over other types of firms can also be expected in the case of Colombia. Based on this, the first hypothesis is the following:

> *Hypothesis 1: The foreign subsidiaries in the Colombian manufacturing sector are more innovative than national firms.*

Following Criscuolo et al (2010), the second hypothesis is defined in relation to the factors that explain the technological superiority of foreign subsidiaries. In particular, we address the argument that there is a positive relationship between firms' internationalization and innovation capacities, the second hypothesis is defined as follows:

> *Hypothesis 2: The innovation superiority of foreign subsidiaries firms can be explained by the fact that they make more intensive use of internal and external knowledge inputs than their domestic counterparts.*

3. Methodology

3.1. Empirical model

We develope a comparative analysis of the innovation performance between foreign owned subsidiaries and domestic firms, combining the methodological approximation proposed by Criscuolo et al (2010) and the application of a reduced CDM model. Particularly, we estimate the innovation investment and knowledge production function (KPF) equations, excluding productivity analysis. The CDM model attempts to correct two main econometric problems: (i) selection bias which is associated with the fact that only a small number of firms make or report innovation investment (Griffith et al., 2006) and (ii) endogeneity problems, given that innovation expenditures are endogenous in the KPF.

Unlike the original CDM model, and following contributions of Bogota Manual to measure innovation (Jaramillo et al., 2000), we consider a broad range of technological activities and not only expenditures on R&D and total innovation investment, such as intramural and extramural R&D, incorporated technology (i.e. capital goods as machinery and equipment) and unincorporated technology (technology transfer, licenses and technical assistance). This allows us to make a more suitable comparison of the differences in the technological strategies between foreign and domestic firms[3]. Another of the variations is the distinction between domestic exporting and non-exporting firms, which adds greater robustness to the analysis because allows comparing foreign subsidiaries with firms that are technologically more similar to them (i.e. exporter)[4].

The general model is a system of four equations in which **Equation 0** represents the efforts of firms in innovation activities, i =1,…N being the sub-index relative to firms:

Equation 0

$$g_i^* = \beta_0 x_{0i} + \varepsilon_{0i}$$

where, g_i^* is a latent unobserved variable, x_{0i} is the vector of determinants of innovation efforts, β_0 is the vector of parameters of interest, and ε_{0i} is the error term. Give that equation 0 cannot be estimated directly, the innovation effort (g_i^*) is approximated through the innovation investment, which is denoted by g_i, only if the firm makes or reports such expenditures. Consequently, the following equation describes whether or not firms invest in innovation activities:

Equation 1

$$g_i = \begin{cases} 1 & \text{si } g_i^* = \beta_1 x_{1i} + \varepsilon_{1i} > c \\ 0 & \text{si } g_i^* = \beta_1 x_{1i} + \varepsilon_{1i} \leq c \end{cases}$$

where g_i is a dummy variable equal to 1 for firms that report positive innovation investment, and equal to 0 otherwise; g_i^* represents a decision criterion to carry out innovation activities, for example, the invest expected return - which should be greater than a threshold c for the firm that decides to invest in these activities; x_{1i} is the vector of explanatory variables that influence the decision to invest in innovation

activities (among these, be a foreign subsidiary), β_1 is the vector of the parameters to be estimated and ε_{1i} is the random error terms.

The following equation refers to innovation effort of firm *i*, conditioned to the firm report a positive innovation investment:

Equation 2

$$k_i = \begin{cases} k_i^* = \beta_2 x_{2i} + \varepsilon_{2i} & \text{si } g_i = 1 \\ 0 & \text{si } g_i = 0 \end{cases}$$

where k_i is the logarithm of innovation investment (defined as the ratio of innovation expenditures to the number of employees), x_{2i} is the vector of determinants of innovation effort, β_2 is the vector of the parameters to be estimated and finally ε_{2i} is the error term. Assuming that the errors ε_{1i} and ε_{2i} correlated in **Equations 1 and 2** and follow a normal distribution, these two equations are estimated jointly through a Heckman selection model (Heckman, 1979). **Table 2** shows the vector of explanatory variables (x_{1i} y x_{2i}), including the type of firm, whether foreign subsidiary, domestic exporter or domestic non-exporter. Detailed description of dependent variables can be found in **Appendix 1**.

Finally, the last equation is the KPF, which describes the process of transformation of innovation inputs into innovation outputs:

Equation 3

$$t_i = \gamma \hat{k}_i + \beta_i x_{3i} + \varepsilon_{3i}$$

Here t_i refers to changes in the knowledge stock proxied by three innovation indicators and ($\hat{k}_i$) i is the predicted innovation effort from **equation 2**, conditional to undertaking innovation activities, which corrects the possible endogeneity of innovation investment in the KPF. The coefficient γ represents the elasticity of innovation output with respect to innovation input. The vector of variables x_{3i}, are the factors that influence knowledge production, β_i is the vector of parameters of interest associated with the remaining explanatory variables and ε_{3i} is the error term.

To estimate t_i we use diverse measures of innovation, which ensures greater robustness for the analysis and allows to overcoming possible measurement errors. We considered the following indicators:

- Incremental innovation: firms that innovate new or significantly improved goods or services for the same firm or the national market (Duguet, 2006).
- Radical innovations: firms obtain new or significantly improved goods or services for the international market (Duguet, 2006).
- Patenting: firms that have sought or obtained patents in the period analyzed.

Given that all the regressors are dichotomous variables, we use a maximum likelihood probit model to estimate the KFP (Long & Freese, 2006). Following Criscuolo et al. (2010), to have a more comprehensive analysis of the explanatory factors that explain the innovation output differences between foreign subsidiaries and domestic firms, we organized the vectors of explanatory variables (x_{3i}) into the

following four groups variables (**Table 3**): (i) type of firm; (ii) knowledge inputs ($\widehat{k_i}$); (iii) knowledge flows from internal and external sources, measured through innovation cooperation with other organizations, and (iv) the remaining variables that can influence the production of innovations according to the CDM model.

Table 2 - Explanatory variables of equations 1 y 2

	Explanatory variables
x_{2i}	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference) Control variables: -Firm size -Innovation protection -Public support -Industrial sector
x_{2i}	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference) Control variables: -Public support -Innovation protection -Innovation cooperation -Internal and external knowledge sources (group, vertical, horizontal and R&D organizations) -Industrial sector

Table 3 - Explanatory variables of equation 3

	Group	*Explanatory variables*
I	Type of firm	-Foreign subsidiary -Domestic exporting firm -Domestic non-exporting firm (reference)
II	Knowledge inputs	-Model 1 (M1): predicted R&D intensity -Model 2 (M2): predicted innovation activities intensity -Model 3 (M3): predicted intensity of the four types of innovation activities separately (Intramural R&D intensity, extramural R&D intensity, incorporated technology intensity and unincorporated technology intensity)
III	Knowledge flows	Group cooperation Vertical cooperation Horizontal cooperation Cooperation with universities and R&D centers
IV	Control variables	-Firm size -Public support -Innovation protection -Industrial sector

To identify the differences between foreign and domestic firms (reference group) in knowledge production, we first estimate t_iwith the variables that indicate the type of firm (Group I) and the control variables (Group IV) to test whether multinationals generate more knowledge outputs than domestic firms do. Secondly, if it is confirmed that multinationals generate more innovation outputs, the knowledge inputs variables are added (Group II). Finally, we add knowledge flows variables (Group III) to determine if the residual variation is explained by the presence of foreign capital. It should be noted that the estimated coefficient for the variable "foreign subsidiary" (i.e. marginal effect) captures the differences in innovation performance among subsidiaries and exporting and non-exporter domestic firms.

Then we made an "innovation accounting" exercise that allows us to identify the main factors that explain the knowledge production differences between foreign and domestic firms (Criscuolo et al., 2010). This methodology proposes that the differences in innovation output among periods of time of units or firms can be the result of changes in the factors that determine innovation plus a residual called "innovativeness", similar to "productivity" (Mairesse & Mohnen 2002)[5]. As with the case of Total Productivity Factors (TPF), this residual can be associated with omitted factors such as business performance, organizational competences, cultural issues or environmental factors; although it can also be due to specification errors. This exercise is conducted only when the foreign firm status has a statistical and significant effect on the measures of innovation that we are considered in the estimation.

3.2. Data

The firm level database used in the empirical analysis is obtained from the merge of the fourth Development and Technological Innovation Industrial Survey (EDIT, for its acronym in Spanish) and the Annual Manufacturing Survey (Encuesta Anual Manufacturera, henceforth EAM), both collected by the National Administrative Department of Statistics (DANE). The former follow the conceptual guidelines of Oslo and Bogota Manual and its purpose is to characterize innovation activities in Colombian manufacturing sector. This survey provides information from 2007 and 2008 and is applied to the firms included in the company directory used in EAM. The second is a survey of industrial establishments with ten or more employees or with a level of production higher than the value stipulated for each year as a reference and provides general economic data on firm characteristic and performance variables. Merging these two databases we obtained 7,069 observations of which 476 are foreign subsidiaries, 1,692 are domestic exporting firms, and 4,901 are domestic non-exporting firms[6].

Although actually are available the seventh version of the EDIT (2013-2014), we opt to use the data for 2007-2008 for several reasons: The first one is our objective to analyze innovation performance of foreign subsidiaries prior to the economic crisis that reduced significantly FDI flows into developing countries; secondly, to capture the moment and effects of the significant growth of foreign invesment toward manufacturing sector in Colombia, which can be attributed to policy reforms made in 2002 for attracting higher FDI (Fedesarrollo, 2007); and third, because these data allow us to compare the results with the prior evidence for Colombia that also uses data for the same period or earlier (Arbelaez & Parra, 2007; Garrido et al., 2015).

Although foreign subsidiaries are only 6.6 per cent of the manufacturing firm, they contribute significantly to industrial aggregates such as sales, employment and industrial R&D and innovation investment (**Table 4**).

Table 4 - Contribution of foreign subsidiaries to industrial aggregates (in %)

	Foreign subsidiaries	Domestic exporting firms	Domestic non-exporting firms
Firms	6,6	23,0	70,4
Sales	33,1	43,00	23,9
Employment	23,8	40,2	36
I&D investment	23,1	51,2	25,7
Innovation investment	30,3	46,8	22,9

Source: Own calculation based on EDIT IV and EAM (DANE)

Table 5 shows the average of the main variables of the model by type of firms and the correlations among the variables are presented in Appendix 2. In all of these measures, foreign subsidiaries are superior to the other firms, providing a preliminary indication that there are differences between this type and domestic firms in their innovative capacities. However, we observe that the differences between foreign subsidiaries and domestic exporting firms are not as wide as expected.

Table 5. Comparisons of innovation inputs, innovation outputs and knowledge flows (on average)

Indicator	Foreign subsidiaries	Domestic exporting firms	Domestic non-exporting firms
Innovation inputs: probability			
R&D (% firms)	20.6	17.0	7.5
Intramural R&D (% firms)	19.5	15.7	6.8
Extramural R&D (% firms)	5.9	4.3	1.9
Incorporated technology (% firms)	52.5	47.5	30.4
Unincorporated technology (% firms)	23.9	17.3	9.2
Innovation activities investment (% firms)	57.1	51.4	33.7
Innovation inputs: innovation effort			
R&D intensity*	512	401	223
Intramural R&D intensity*	425	348	190
Extramural R&D intensity*	86	53	33
Incorporated technology intensity*	6,607	4,099	1,680
Unincorporated technology intensity*	1,161	2,221	96
Innovation activities intensity*	8,993	5,177	2,185
Innovation outputs			
Incremental innovation (% firms)	42.6	38.7	25.1
Radical innovation (% firms)	13.9	12.1	1.6
Patenting (% firms)	4.6	2.4	1.0
Knowledge flows			
Group	16.4	8.3	3.1
Vertical	26.7	24.6	12.2
Horizontal	3.8	3.0	2.0
Universities and R&D centers	12.6	11.8	4.3

Source: Own calculation based on EDIT IV and EAM (DANE)
*Values in thousands of pesos at 2008 prices.

4. Results

4.1. Innovation inputs

Table 6 shows the results of the estimation of the engagement in innovation activities and innovation intensity equations. We report marginal effects at the sample mean[7]. Given that the *Rho* estimator in all the estimations is statistically significant it is appropriate to use the Heckman selection method. The first result to highlight is that foreign subsidiaries do not have a higher probability of investing in R&D and innovation activities than domestic firms, especially compared to national exporting companies. At a more disaggregated level, subsidiaries have a higher probability of investing in intramural R&D and unincorporated technology than domestic firms. Although, in the case of intramural R&D, the estimated marginal effects are lower than the level revealed by domestic exporting firms.

Table 6. Estimation innovation activities equations

Tipo de actividad		Foreign subsidiaries	Domestic exporting firms	Rho	Wald chi2
R&D	Probability	0,021	0.040***	0.848***	78.4***
		(0,014)	(0,009)		
	Intensity	0.535**	0.370***		
		(0,235)	(0,139)		
Intramural R&D	Probability	0.026*	0.040***	0.859***	77.2***
		(0,014)	(0,009)		
	Intensity	0,337	0.382***		
		(0,240)	(0,146)		
Extramural R&D	Probability	0,002	0,004	1.199***	33.7***
		(0,006)	(0,004)		
	Intensity	0.917**	0.453*		
		(0,493)	(0,270)		
Innovation activitics	Probability	0,027	0.066***	0.636*	222.1***
		(0,026)	(0,016)		
	Intensity	0.626***	0.309***		
		(0,119)	(0,068)		
Incorporated technology	Probability	0,024	0.064***	0.740*	117.2***
		(0,026)	(0,015)		
	Intensity	0.508***	0.218***		
		(0,131)	(0,076)		
Unincorporated technology	Probability	0.028*	0.025***	0.861***	118.0***
		(0,016)	(0,009)		
	Intensity	1.123***	0.361***		
		(0,204)	(0,124)		

Source: Own calculation based on EDIT IV and EAM (DANE)

Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis. Observations: 7,069 firms

* Significant at 10% ** Significant at 5% *** Significant at 1%.

Concerning to innovation intensity equations, foreign subsidiaries have more intensive expenditures in R&D and in total innovation activities that domestic firms, both exporters and non-exporters. The superior investment in R&D can be explained mainly by extramural activities[8] that are based on the association with other organizations. Foreign subsidiaries are also more intensive than domestic firms in activities that require intermediate or basic capacities such as the acquisition of incorporated and unincorporated technology. This result suggests that the technological strategies of foreign subsidiaries in Colombia are more related to the need to establish technological facilities than with the generation of new knowledge, i.e. the predominance of knowledge exploiting strategies based on already existing technological competencies in the multinational group.

The neutral effect of being a foreign firm on the probability of undertaking R&D activities and the positive impact on the investment intensity are in line with the results of Romo & Hill (2006) for Mexico. The behavior in total spending on innovation is also consistent with the evidence provided for Masso et al. (2012) for Estonia, Cassoni & Ramada (2010) for Uruguay, and Arbeláez & Parra (2010) and Gallego et al. (2015) for Colombia.

4.2. Innovation outputs

The estimation results of knowledge output are detailed in **Table 7** containing the marginal effects of the main explanatory variables. We include various versions of the KFP to assess whether foreign subsidiaries have an advantage in the innovation outputs and in the use of inputs and knowledge flows. Considering incremental innovation, with the exception of the reduced model (M0), the relationship between incremental innovation and the condition of being a subsidiary is negative and statistically significant.

In contrast, foreign subsidiaries have greater probability of obtaining radical innovations, and patenting (the latter only in M1 and M3) relative to the reference category of local firms. Domestic exporting firms also have a greater probability of making innovations for the international market and patenting than domestic non-exporting firms, but the associated marginal effects are somewhat less than those in the case of subsidiaries. This evidence is consistent with that provided by Arbeláez and Parra (2010), although these authors used an econometric specification and a different indicator to assess the effect of foreign ownership on innovation outputs.

When we include inputs and knowledge flows (different types of cooperation) in the model of radical innovation, the marginal effect and their statistical significant it is not greatly affected in M1 but if in M2 and M3 models. Here marginal affects attributed to foreign firms decreases substantially (the probability of obtaining radical innovations goes from 7.7% to 1.7% in M2 and to 3.0% in M3). The trend is different in the case of the patenting probability, given that the marginal effect of being a foreign firm is higher with the inclusion of spending on R&D and cooperation variables in M1 and M3 models.

It can be argued that the superiority of subsidiaries in obtaining radical innovations is related to the strong export orientation of foreign subsidiaries in Colombia (around 74% of subsidiaries are exporters). The results could also indicate the possible presence of foreign firms with competences creating strategies that generate competitive advantages in international markets through, for example, the adaptation of innovations to sub-regional markets (e.g. Andean countries) already present in the product range of the multinational group (Papanastasslou & Pearce, 1997; Pearce, 1999). The greater probability of

subsidiaries to take out patents could be related to the need of protecting already existing innovations in the multinational group (Criscuolo et al, 2010) not only in the national market but also with the possible extension to sub-regional markets, which could be due to the effect of trade agreements with countries in the region in which there are special agreements for the protection of intellectual property.

Table 7. Estimation of the innovation outputs

Variables independientes	Incremental innovation				Radical innovations				Patenting			
	M0 [a]	M1[b]	M2[c]	M3[d]	M0 [a]	M1[b]	M2[c]	M3[d]	M0 [a]	M1[b]	M2[c]	M3[d]
Tipo de empresa												
Foreign subsidiary	-0,018	-0.073***	-0.246***	-0.238***	0.077***	0.062***	0.017*	0.030**	0.014**	0.018**	0,006	0.017*
	(0,023)	(0,023)	(0,017)	(0,018)	(0,016)	(0,015)	(0,009)	(0,014)	(0,007)	(0,008)	(0,005)	(0,010)
Domestic exporting firm	0.033**	-0.045**	-0.290***	-0.451***	0.072***	0.054***	0.018***	-0,006	0.005*	0.008**	0,001	0,001
	(0,014)	(0,019)	(0,027)	(0,022)	(0,008)	(0,009)	(0,007)	(0,007)	(0,003)	(0,004)	(0,003)	(0,004)
Inputs												
R&D		0.175***				0,009				0.006*		
		(0,045)				(0,008)				(0,004)		
Innovation activities			0.630***				0.037***				0.007***	
			(0,071)				(0,007)				(0,003)	
Intramural R&D				-0,020				0.047**				0,002
				(0,141)				(0,022)				(0,009)
Extramural R&D				3.307***				0.092***				0,017
				(0,349)				(0,035)				(0,013)
Incorporated technology				1.449***				0.073***				0.010**
				(0,096)				(0,011)				(0,004)
Unincorporated technology				-1.112***				-0.076***				-0,015
				(0,171)				(0,022)				(0,010)
Knowledge flows												
Gruop		0.061*	-0,003	-0.064**		0.017*	0,011	0,006		0,000	-0,002	-0,001
		(0,033)	(0,035)	(0,032)		(0,009)	(0,007)	(0,007)		(0,003)	(0,002)	(0,002)
Vertical		0.363***	0.204***	0.226***		0.045***	0.024***	0.028***		0,003	0,001	0,002
		(0,019)	(0,026)	(0,024)		(0,008)	(0,007)	(0,007)		(0,003)	(0,003)	(0,003)
Horizontal		0.080*	0,062	0,073		0,001	0,003	0,002		0,002	0,002	0,002
		(-0,048)	(-0,050)	(-0,052)		(-0,008)	(-0,007)	(-0,008)		(-0,003)	(-0,003)	(-0,003)
Universities/R&D centers		0.083***	0,013	-0,019		0.020**	0.014**	0.014**		0,007	0,005	0,006
		(0,030)	(0,033)	(0,032)		(0,008)	(0,007)	(0,007)		(0,005)	(0,004)	(0,004)
Log likelihood	-3864,3	-3531,7	-3212,8	-2967,9	-1129,1	-1056,4	-1023,9	-998,9	-476,5	-471,7	-469,6	-466,3
Wald chi2	802.3***	1076.5***	1054.9***	1077.5***	426.8***	567.6***	655.2***	751.5***	216.8***	207.2***	221.4***	199.0***
Pseudo R2	0,10	0,18	0,25	0,31	0,19	0,24	0,27	0,28	0,17	0,18	0,18	0,19

Source: Own calculation based on EDIT IV and EAM (DANE)

Note: the conditional marginal effects are reported at the sample mean and robust standard deviation in parenthesis. Observations: 7,069 firms

*Significant at 10% ** Significant at 5% *** Significant at 1%

[a] M0: is the estimated reduced model with the variables of the type of firm and the basic control variables.

[b] M1: includes the estimated intensity of investment in R&D as an explanatory variable.

[c] M2: includes the estimated intensity of investment in innovation activities as an explanatory variable.

[d] M3: includes the separately estimated intensity of investment in the four innovation activities as explanatory variables.

4.3. Innovation accounting

Following Criscuolo et al. (2010), in this section we seek to distinguish if innovation-output advantage of foreign subsidiaries is accounted for by their greater use of inputs or their ability to access and use local and global knowledge, and how much is left unexplained.

Tables 8 and 9 show the innovation accounting results for radical innovation and patenting estimations, aspects in which subsidiaries have advantages in all versions of the KPF (see **Table 7**). Here, raw foreign subsidiary–domestic differential is calculated using the data of **Table 5**, obtained by subtracting the average values of the innovation variables between foreign firms and domestic non-exporting firms expressed as a percentage (e.g. for radical innovation: 13.9-1.6=12.3%).

Using the data of **Table 7**, the adjusted differential for innovation outputs is the marginal effect estimated for foreign subsidiaries in KFP versions, also expressed in percentage. For example, in the case of radical innovation the adjusted differential is the marginal effect of the "subsidiary" variable in M0, in column 5 of **Table 7** (that is, 7.7%). The next rows in **Tables 8 and 9**, represents the share of the adjusted differential that is explained by the differential use of innovation inputs and knowledge flows between foreign firms and domestic non-exporting firms. For radical innovation, the part of the adjusted differential that is explained by R&D investment is 1.7%.

Finally, the unexplained differential fraction reports the shared of adjusted differential that is unexplained by the estimated regressors, that is, the *per se* effect of being a foreign firm[9]. Taking into account radical innovation, this value is obtained dividing the marginal effect of foreign subsidiaries in M1 over the adjusted differential obtained in the reduced model (M0) (80.5= (6.2/7.7). This surplus margin can be attributed to the characteristic of being a foreign subsidiary.

Table 8. *Innovation Accounting-R&D* (in %). Subsidiaries versus domestic non-exporting firms (Models 1 and 2)

Item	M1		M2	
	Radical innovation	Patenting	Radical innovation	Patenting
Raw foreign subsidiary–domestic differential (observed)	12.3	3.6	12.3	3.6
Adjusted foreign subsidiary–domestic differential (Estimated)	7.7	1.4	7.7	1.4
Fraction of adjusted differential accounted for by:				
Inputs				
R&D intensity	0.01	0.03		
Innovation activities intensity			0.038	0.04
Knowledge flows				
Gruop	2.94	0.03	1,38	-1,9
Vertical	8.47	0.10	4,52	1,04
Horizontal	-0.02	3.11	-0,07	-0,26
Universities/R&D centers	2.16	-0.26	1,51	2,96
Unexplained differential fraction	**80.5**	**128.6**	**22.1**	**42.9**

Source: Own calculation based on EDIT IV and EAM (DANE)

In relation to the results in **Table 8**, it should be noted firstly that the superiority of foreign firms in radical innovation is explained more by a greater use of external knowledge flows than by efforts made at R&D; especially, the cooperation with other organizations in the value chain, multinational group and universities and R&D centers. Considering patenting estimation, R&D activities are much more important, while the knowledge acquired externally has a negligible effect. The high value of the unexplained differential (between 75% and 80%, for radical innovation and patenting respectively) implies that much of the difference in knowledge production is explained by the fact of being a foreign subsidiary.

The results shown in **Table 9** provide additional information taking into account a broad range of technological activities. We observe that other innovation inputs are much more important that R&D, such as incorporated and unincorporated technology. In addition, it is observed that the unexplained differential fraction is much lower (36%), which indicates that the model seems to adjust better to the process to obtaining radical innovations (in the case of patenting is similar). In particular, it suggests that the superiority of foreign subsidiaries in innovation production is the result of the combined use of internal inputs of greater scale, like R&D, and others that require intermediate or basic capacities, like the acquisition of incorporated technology. In term of knowledge flows, is important the vertical cooperation (clients and suppliers) and with Universities/R&D centers.

Table 9. *Innovation Accounting*- (%) (M3) Subsidiaries versus domestic non-exporting firms (Model 3)

Item	M3	
	Radical innovation	Patenting
Raw foreign subsidiary–domestic differential	12,3	3,6
Adjusted foreign subsidiary–domestic differential	7,7	1,4
Fraction of adjusted differential accounted for by:		
Inputs		
Intramural R&D	7,7	13,6
Extramural R&D	14	18,4
Incorporated technology	60,5	31,9
Unincorporated technology	-97,4	35,2
Knowledge flows		
Gruop	1	-1
Vertical	5,3	2,1
Horizontal	-0,05	-0,3
Universities/R&D centers	1,5	3
Unexplained differential fraction	**36,4**	**85,7**

Source: Own calculation based on EDIT IV and EAM (DANE)

5. Conclusions

The possibility of knowledge flows from foreign subsidiaries to the host economies depends on their innovation capacities. This aspect justifies the interest of this contribution, which analyzes the innovation performance of foreign subsidiaries in Colombian manufacturing sector, compared to their domestic counterparts and the explanatory factors of these divergences.

Our main findings are as follows. First, foreign subsidiaries reveal a similar probability to undertake R&D and innovation activities compared to domestic firms, especially those that export. Concerning to innovation effort, foreign subsidiaries show a greater intensity in R&D and innovation activities than exporting and non-exporting domestic firms. However, the major efforts of foreign firms are in extramural R&D activities (carried out by public or private organizations) and other innovation lower-order activities like the investment in incorporated (e.g. machinery and equipment) and unincorporated technology.

Second, the estimation of the knowledge production function shows that foreign subsidiaries have a lower innovation performance than domestic firms in the case of incremental innovations. However, subsidiaries show a greater probability of obtaining radical innovations (toward the international market) and to patent inventions. The importance of radical innovation in foreign subsidiaries can be related with their strong export orientation and the connection of the Colombian economy with sub-regional markets through exports.

Third, the *innovation accounting* exercise explains the sources of differences in innovation performance, and it confirms that foreign firms use comparatively greater internal and external knowledge inputs to produce radical innovations and patenting. At the internal level, activities that require intermediate or basic technological capacities predominate, while at the external level are important knowledge flows with the multinational groups and with organizations of the national innovation system (clients and suppliers, and, to a lesser degree, universities and research centers).

One result to highlight is that in contrast to prior evidence about the relationship between internationalization and innovation in more developed countries (Wagner, 2006; Castellani & Zanfei, 2007; Criscuolo et al., 2010), subsidiaries of multinational firms in Colombia have a similar innovation performance that national firms connected to international markets. Also, the evidence suggest that the foreign subsidiaries in Colombia seem to have distinct mandates, combining strategies of the creation and exploitation of competencies, the latter being the more dominant. That is, multinationals decide to locate R&D and innovation activities to exploit their competitive advantages in the Colombian or sub-regional market more than to create new technological capacities for the group. However, to affirm this more conclusively in-depth study is required in future research.

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Notes

2. As well as productivity, there are differences between national and foreign firms in wages, human capital and growth (Bellak, 2004).

3. We opted for not including others innovation activities such as training, design and innovation marketing to avoid potential problems of multicolinearity.

4. The study has one important limitation: the lack of information to identify –domestic- Colombian multinational subsidiaries to compare more appropriately the innovation performance of foreign subsidiaries.

5. Innovation can be understood as the ability or capacity to convert innovation inputs into innovation outputs.

6. The sample used in the analysis includes all firms and not just innovative ones (Griffith et al., 2006). This is because the design and application of the innovation survey for Colombia follows the Bogotá Manual in terms of the importance of identifying "innovation effort" of firms independent of their success at innovation (Jaramillo et al., 2000).

7. Only the marginal effect is comparable to OLS coefficients, for both selection and intensity equations (Hoffmann & Kassouf, 2005).

8. In domestic firms, extramural R&D invesment is 12%; in foreign subsidiaries, this percentage reaches 45%.

9. For more details on the calculation see Criscuolo et al. (2010).

Appendix 1. Definition of variables

Dependent variables

Indicator	*Definition*
R&D (Probability)	Dummy equal to 1 if the firm has made investments in R&D and equal to 0 otherwise.
Intramural R&D (Probability)	Dummy equal to 1 if the firm has made investments in intramural R&D and equal to 0 otherwise.
Extramural R&D (Probability)	Dummy equal to 1 if the firm has made investments in extramural R&D and equal to 0 otherwise.
Incorporated technology (Probability)	Dummy equal to 1 if the firm has made investments in incorporated technology and equal to 0 otherwise.
Unincorporated technology (Probability)	Dummy equal to 1 if the firm has made investments in unincorporated technology and equal to 0 otherwise.
Innovation activities investment (Probability)	Dummy equal to 1 if the firm has made investments in innovation activities and equal to 0 in otherwise.
R&D (Intensity)	R&D investment per employee (in logs)
Intramural R&D (Intensity)	Intramural R&D investment per employee (in logs)
Extramural R&D (Intensity)	Extramural R&D investment per employee (in logs)
Incorporated technology (Intensity)	Incorporated technology investment per employee (in logs)
Unincorporated technology (Intensity)	Unincorporated technology investment per employee (in logs)
Innovation activities investment (Intensity)	Total Innovation activities investment per employee (in logs)
Incremental innovation	Dummy equal to 1 if the firm has obtained goods or services new or significantly improved to itself or to the national market and equal to 0 otherwise.
Radical innovation	Dummy equal to 1 if the firm has obtained goods or services new or significantly improved to itself or to the international market and equal to 0 otherwise.
Patenting	Dummy equal to 1 if the firm has applied for or obtained patents of invention and equal to 0 otherwise.

Explanatory variables

Indicator	*Definition*
Foreign subsidiary	Dummy equal to 1 if the firm has a foreign capital greater than 25% and equal to 0 otherwise
Domestic exporting firm	Dummy equal to 1 if the firm has exported and equal to 0 otherwise
Domestic non-exporting firm (reference)	Dummy equal to 1 if the firm has not exported and equal to 0 otherwise
Size	Large: Dummy equal to 1 if the firm has more than 200 employees and equal to 0 otherwise
	Medium: Dummy equal to 1 if the firm has between 50 and 200 employees and equal to 0 otherwise
	Small: Dummy equal to 1 if the firm has fewer than 50 employees and equal to 0 otherwise
Demand pull	Environmental and safety aspects: Dummy equal to 1 if the firm respond, with a high importance degree, that innovation has an impact on dumping reduction or toxic emissions, as well as improvement in the industrial safety conditions. Equal to 0 otherwise.
	Regulation and standards: Dummy equal to 1 if the firm respond, with a high importance degree, that innovation has an impact on the fulfillment of regulations, standards and technical regulations. Equal to 0 otherwise.
Innovation cooperation	Dummy equal to 1 if the firm cooperated with other actors in innovation activities and equal to 0 otherwise.
Knowledge flows: Group	Dummy equal to 1 if the firm cooperated with their corporate group in innovation activities and equal to 0 otherwise.
Knowledge flows: Vertical	Dummy equal to 1 if the firm cooperated with clients and suppliers in innovation activities and equal to 0 otherwise.
Knowledge flows: Horizontal	Dummy equal to 1 if the firm cooperated with competitors in innovation activities and equal to 0 otherwise.
Knowledge flows: Universities/R&D centers	Dummy equal to 1 if the firm cooperated with Universities or R&D centers in innovation activities and equal to 0 otherwise.
Public support	Dummy equal to 1 if the firm receives public support to develop innovation activities and equal to 0 otherwise.
Innovation protection	Dummy equal to 1 if the firm protects their innovations through patents, utility models, copyright, industrial designs, distinctive signs and marks. Equal to 0 otherwise.
Sector	R&D intensive sector: CIIU 15,16, 26, 27, 34 y 35
	Scale intensive sector: CIIU 17, 18, 19, 20, 21, 22 y 25
	Specialized suppliers sector: CIIU 23, 24, 31 y32
	Dominated by supplier's sector: CIIU 28, 29 y 33
Information sources: Group	Dummy equal to 1 if the firm uses as innovation sources of information their parent company or other related companies. Equal to 0 otherwise.
Information sources: Vertical	Dummy equal to 1 if the firm uses as innovation sources of information clients and suppliers. Equal to 0 otherwise.
Information sources: Horizontal	Dummy equal to 1 if the firm uses as innovation sources of information their competitors. Equal to 0 otherwise.
Information sources: Universities/R&D centers	Dummy equal to 1 if the firm uses as innovation sources of information universities and R&D centers. Equal to 0 otherwise.

Appendix 2. Pairwise correlations

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Foreign subsidiary	1.00															
2	Domestic exporting firm	-0.39	1.00														
3	R&D intensity (Log)	0.05	0.23	1.00													
4	Innovation activities intensity (Log)	0.18	-0.03	0.35	1.00												
5	Intramural R&D intensity (Log)	0.08	0.26	0.97	0.34	1.00											
6	Extramural R&D intensity (Log)	0.03	0.06	0.74	0.25	0.60	1.00										
7	Incorporated technology intensity (Log)	0.19	0.04	0.39	0.65	0.36	0.27	1.00									
8	Unincorporated technology intensity (Log)	0.05	0.08	0.58	0.37	0.54	0.56	0.33	1.00								
9	Information sources: Gruop	0.13	-0.03	0.08	0.06	0.09	0.00	0.02	-0.03	1.00							
10	Information sources: Vertical	0.31	-0.10	0.16	0.35	0.18	0.00	0.25	0.18	0.09	1.00						
11	Information sources: Horizontal	0.15	0.07	-0.04	-0.08	-0.01	-0.07	-0.02	0.05	0.13	0.00	1.00					
12	Information sources: Universities/R&D centers	0.10	-0.02	-0.10	0.01	-0.12	-0.12	0.03	-0.07	0.32	0.06	0.36	1.00				
13	Knowledge flows: Gruop	0.05	0.17	0.33	0.23	0.28	0.24	0.19	0.34	0.11	0.44	0.00	0.04	1.00			
14	Knowledge flows: Vertical	0.05	0.08	0.02	0.05	-0.02	0.01	0.07	0.08	0.21	0.13	0.09	0.28	0.38	1.00		
15	Knowledge flows: Horizontal	0.19	0.13	0.03	0.14	0.08	-0.04	0.02	0.12	0.06	0.08	0.40	0.11	0.34	0.29	1.00	
16	Knowledge flows: Universities/R&D centers	0.06	0.25	0.25	0.04	0.28	0.03	0.03	0.10	0.14	0.12	0.18	0.09	0.25	0.34	0.30	1.00