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FOREIGN TRADE, EDUCATION, AND INNOVATIVE PERFORMANCE: A MULTILEVEL ANALYSIS

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ABSTRACT

This study analyses the innovative performance of 5,273 companies across 64 different economic sectors and 32 different regions in Colombia. We assess the effects of education and open economy variables on the innovative performance of firms by analyzing firm, sectoral, and regional level determinants. The study takes the multilevel approach of the innovation process considering the structure and behavior of innovation systems in developing countries. We furthermore focus on technology transfer from foreign trade and the role of education in the process of innovation. We find that education and open economy variables have a significant relationship with innovation performance at the firm and regional levels. We finally conclude that Colombia has a fragmented innovation system with a weak institutional structure, and low interaction between policymakers, industry, universities, research centers.

Keywords: Multilevel approach; Innovative performance; Open economy variables; Innovation systems; Multilevel regression models; Development.
JEL Classifications: O31; O32.

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I. INTRODUCTION

What are the roles of education and Open Economy Variables (OEV) in the innovative performance of Colombian manufacturing firms? In support of the Innovation System (IS) theory, it has been found that both education and foreign trade are crucial in the development of new knowledge, technology transfer, and knowledge spillovers (Keller, 2010; Lundvall *et al.*, 2009; Srholec, 2011, 2015). Recent contributions to the literature have not only shown that the educational institutions in Colombia should be capable of transferring knowledge to the industry (Vélez-Rolón *et al.*, 2020), but also confirmed that imports are positively related with science, technology, and innovation activities (Guevara-Rosero, 2020)

Seminal studies on the IS theory were conducted by Lundvall (1985) and Freeman (1982). While Lundvall (1985) analyzed innovation at the micro-level, whereby the user-producer interactions shaped the development of new technologies and products, Freeman (1982), from a macro-perspective, underlines the relation between innovation and international trade, emphasizing the importance of building a technological infrastructure at the national level. From this macro perspective, company innovation is at the center of analysis but is seen in the larger context of the network of institutions, whose interactions enable the diffusion of new technologies. Firms are exposed to a context in which international trade (Laurin and St-Pierre, 2011) and capital mobility (Keller, 2010) become a bridge of technology transfer between the global knowledge networks and the IS. In addition, universities play a significant role in the formation of human capital and scientific research. These education institutions provide skilled labor, while also being a source of specific knowledge transfer for different industries (OECD, 2012; UNCTAD, 2014). In Latin America, however, cross-country analysis of innovation performance at the firm level has encountered two main constraints. First, the enforcement of new legislations that control the access to microdata files in different countries (Guillard and Salazar, 2017). Second, differences in data collection procedures among Latin American countries often prevent meaningful comparisons across countries (Guillard and Salazar, 2017). So far, studies on Colombia that relate innovation systems with multilevel models have been limited to two levels, *viz.*, firm and regional levels (Barrios-Aguirre, 2013; Zuluaga Jiménez *et al.*, 2012). This study adds to the literature by considering an additional dimension of sectoral innovation, which allows us to perform a three-level analysis (i.e., firm, sector, and region). Accordingly, the main objective of this research is to determine whether OEV and education variables have a significant relationship with the innovative performance of Colombian manufacturing firms considering a multilevel analysis.

This paper presents a multilevel quantitative technique to analyze the innovative performance of the manufacturing industry in Colombia based on the theory of regional and sectoral IS. In particular, the microdata from the Technological Development and Innovation Survey (EDIT) 2007-2008 and merging different datasets mainly provided by the National Department of Statistics (DANE) allows us to build a database that has a hierarchical structure in which companies can be classified according to their economic activities (or sector) and regions in which those firms have their headquarters. By doing so, this study examines 5273 firms operating in 64 different economic sectors and 32 regions in Colombia.

The major conclusion of this study is that, at the firm level, foreign capital harms innovation performance unless firms allocate the foreign capital inflows to R&D activities. At the sectoral level, however, we find weak statistical evidence regarding the influence of OEV variables on innovation performance. At the regional level, foreign trade has a positive influence on innovation performance due to technology transfer. In addition, tertiary education plays a significant role in the development of innovation at the firm and regional levels, hence, indicating the importance of strengthening the university–industry collaboration in the Colombian innovation system.

This paper is organized as follows. Section II introduces the multilevel regression model and the variables. In Section III, we present the data and it is followed by Section IV, estimation of the model, and the results. Then, in the final section (Section V), we conclude the paper and make policy implications.

II. METHODOLOGY

A. From Multilevel Analysis to Multilevel Modeling

In general, individuals interact in a social environment to which they belong. As a result of this, individuals are influenced by this social environment and vice versa (Gupta *et al.*, 2007). In other words, individuals are nested within social groups at different levels creating a hierarchical interconnected structure. A commonality among multilevel regression models[1] is the hierarchical structure of data with the dependent variable at the lowest level and the independent variables at highest levels (Gelman and Hill, 2006; Hox *et al.*, 2017). Multilevel Poisson regression analyses have been used by different disciplines that study embedded data of multilevel phenomena. The reliability of the model depends on the quality of the data as well as the adopted methodology in the estimation process. As the innovation process happens in the firm, sectors, and regions, there are some unobserved conditions by the model. Heterogeneity or variations across individuals, such as firms, sectors, and regions, are unobserved by the model (Hox *et al.*, 2017; Wooldridge, 2002). However, if we use multilevel models with random parameters and mixed effects the unobserved individual-specific heterogeneity is assumed to be unrelated to the explanatory-variable vector. Following Gupta *et al.* (2007), in the field of innovation, the hierarchical structure is visible as firms appear to be the individuals that are clustered in sectors, and these sectors are allocated within regions.

Considering the challenges involved in explaining the causality between the variables of interest and innovation performance, this study proposes the following hypothesis:

> ***H1:*** *Innovative performance is significantly related to open economy variables even though the nature of the relation varies at the regional, sectoral, and firm levels in developing economies.*

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[1] Random coefficient models, variance component models, hierarchical linear models, mixed effect models, and so on (Hox *et al.*, 2017).

According to Fagerberg *et al.* (2009), education is one of the main components of the social capabilities in IS. Thus, we hypothesize that:

H2: *From the multilevel dimensional perspective, higher education, such as a doctorate, master, undergraduate, or associate degree, is expected to contribute to the firm's innovation performance.*

B. Determinants of Innovation from a Multilevel Dimension

From the multilevel dimensional perspective, each of the three levels will encompass a set of determinants that are linked to the main components of the Regional Innovation Systems (RIS) (Padilla-Pérez *et al.*, 2009), the building blocks of Sectoral Innovation Systems (SIS) (Joseph, 2009; Malerba, 2002; Srholec, 2011), and the firms' characteristics (Hadhri *et al.*, 2016).

B.1. Regional Level Determinants

The regional level determinants encompass characteristics outside the firm that can influence innovation performance. Within the context of developing countries, the determinants tend to change due to the existence of heterogeneity across countries and regions (Srholec, 2015). According to the characteristics of the Colombian IS, the following determinants will be tested within the econometric model.

Following the literature, ***imports and exports*** bring along technological and knowledge spillovers that have a positive effect on productivity and innovative performance, nevertheless, the relationship between international trade and innovation in developing countries can bring positive or negative results (Bernard and Bradford Jensen, 1999; Hadhri *et al.*, 2016; Keller, 2010; Lefebvre and Lefebvre, 2002; Padilla-Pérez *et al.*, 2009; Vogel and Wagner, 2010; Juhro *et al.*, 2020). ***Coverage on higher education and human capital*** formation is crucial in the process of innovation (Lundvall, 2015; Juhro *et al.*, 2020; Vélez-Rolón *et al.*, 2020). In developing economies, however, the lack of basic and advanced educational systems and the failure of governments to allocate resources for research and higher education hinder innovation performance (Kuhlmann and Ordóñez-Matamoros, 2017). Technological ***unemployment*** happens when cutting-edge technology disrupts labor markets and creates jobs with high-income cognitive tasks and displace low-income manual occupations and routine tasks (Frey and Osborne, 2017). Evidence from seven Latin American countries, however, shows that investment in science and technology does not affect the unemployment rate (Aguilera and Ramos-Barrera, 2016). The ***distance to the capital city*** and other main cities, geographical proximities to production, skilled labor, high wages, and institutions make interactions, flows of information, and knowledge more effective (Ascani *et al.*, 2012; Feldman and Audretsch, 1999)

B.2. Sectoral Level Determinants

The interactions between the building blocks within the sectoral IS and the main components of the regional IS play a significant role in the exchange of information, knowledge, and technology, as such innovation within sectors takes place (Joseph, 2009). At this level, the following determinants were tested in the econometric model. Similar to the regional level, ***international trade (export rate, trade openness index, foreign capital)*** brings knowledge and technology spillovers that influence innovative performance. Maleçrba (2005) states that firms are embedded in heterogeneous sectors in which they use different technologies, networks, and institutions. Furthermore, trade may bring different effects that could change according to industry characteristics and composition (ICTSD, 2016). Regarding the ***concentration of knowledge,*** Pavitt's Taxonomy distinguishes sectoral innovation patterns considering four types of innovative-firms: science-based, specialized-suppliers, supplier-dominated, and resource-intensive (Bogliacino and Pianta, 2016). On the other hand, Gera and Masse (1996) argue that some industries demand higher R&D investment than others industries, identifying three knowledge intensity groups: high, medium, and low-knowledge industries. The ***concentration of innovation*** takes place on economies of scale, specialized suppliers, and science-based industries, where innovation activities are more intense than industries that are dominated by suppliers (Urraca-Ruiz, 2000). A recent study reveals how digital technologies are redesigning the concentration of innovation activities (Paunov *et al.*, 2019).

B.3. Firm Level Determinants

Innovation performance depends on the characteristics of the firm and the synergy with the regional and sectoral innovation system. Hadhri *et al.* (2016) found that the determinants of innovative performance can change according to the context in which firms are exposed. The following determinants found in the literature are included in our regressions. The ***size*** of companies has a positive relationship with R&D investment (Schumpeter, 1934, 1943). Cohen and Klepper (1996) and Cohen and Levin (1989) claim that larger companies have access to different external technological resources and a higher budget to invest in R&D. Next to size, Hadhri *et al.* (2016) suggest the inclusion of control variables, such as education, networks, human capital, and others. According to Powell and Grodal (2006), ***networks*** foster the trade of knowledge. Nowadays, technology and information flows are important to acquire the knowledge needed to develop and commercialize new products. For this reason, inter-organizational partnerships are important in the development of networks (Ardito *et al.*, 2015). Networks in the era of digital globalization can furthermore generate a suitable environment for innovation performance (Manyika *et al.*, 2018). Evidence also suggests that ***R&D* expenditure** generates a positive effect on innovation and productivity (Baumann and Kritikos, 2016; MacGregor-Pelikánová, 2019; Prodan *et al.*, 2005). In developing countries, however, the resources allocated to R&D are relatively low (Morero, 2017). Hence, the government should create public policies aimed to increase firms' capabilities to absorb foreign knowledge to improve innovation performance and development (Morero, 2017). ***Human capital*** is crucial in the innovative behavior of firms. Romijn and Albaladejo (2002) mentioned the need to have trained and skilled people in areas such as engineering, science, and others. Firms in emerging economies, however, do not have access to a labor force with technological-oriented skills that are needed in the development of high-quality goods and services (Morero, 2017).

In a low-resource context, where there is less collaboration between universities and industry, firms will also have to make more effort to build up their human capital (Albats *et al.*, 2020; Marotta *et al.*, 2007). Finally, the role played by ***Foreign Direct Investment (FDI)*** in innovative performance is significant. The innovation literature (De Marchi and Grandinetti, 2017; Keller, 2010; Morero, 2017; Padilla-Pérez *et al.*, 2009) has mentioned how emerging economies have created policies to attract FDI to promote growth and development, and to facilitate technology transfer. Nevertheless, in some countries, these policies are designed to boost sectors related to commodity extraction. For example, the OECD (2014) indicates that a substantial amount of FDI in Colombia has been captured by the mining sector rather than technologically oriented sectors.

III. DATA AND EMPIRICAL METHODOLOGY

A. Data

The data was taken from different official sources, such as DANE, National Department of Planning (DNP), Ministry of Education, Ministry of Commerce, Industry and Tourism; Directorate of Taxes and National Customs (DIAN), and Procolombia. The latest publicly available version of this survey is the EDIT (2007-2008). In recent years, however, the Colombian government has issued certain laws that restrict access to these databases.

The first- or firm-level data comprises 5273 firms obtained from EDIT (2007-2008). The second- or industry-level data contains 64 groups of economic activities identified according to the International Standard Industrial Classification of All Economic Activities, Rev.3 (ISIC Rev3). The third or regional level data include variables of the 32 departments of regions from Colombia.

To build the database, we develop the following measurements. The dependent variable is the ***total count of innovations***. This variable is the summation of all nine types of innovations (see Table 1) that every firm was able to achieve during the period of the survey. This categorization can be found in the EDIT 2007-2008 survey.

Table 1.
Types of Innovation

This table reports the types of innovation based on the Technological Development and Innovation Survey (EDIT) 2007-2008.

1. New goods or services for the company
2. New goods or services for the national market
3. New goods or services for the international market
4. Goods or services significantly improved for the company.
5. Goods or services significantly improved for the national market.
6. Goods or services significantly improved for the international market.
7. New or significantly improved methods of production, distribution, delivery, or logistics systems, implemented in the company.
8. New organizational methods are implemented in the internal functioning, in the knowledge management system, in the organization of the workplace, or the management of external relations of the company.
9. New or significantly improved marketing techniques (channels for promotion and sale, or significant changes in packaging or product design), implemented in the company to expand or maintain its market. (Changes that affect the functionalities of the product are excluded).

Source. EDIT 2007 -2008

The EDIT 2007-2008 survey classifies three types of innovation, namely radical, incremental, and strategic,[2] and measures the innovation performance by counting the accumulation of innovations within two years. The dependent variable used in this study is the *total count of innovations,* which is the summation of the three above-mentioned types. Table 2 gives the summary statistics of the dependent variable.

Table 2.
Descriptive Statistics of the Total Count of Innovations

This table reports the descriptive statistics of the total count of innovation based on the Technological Development and Innovation Survey (EDIT) 2007-2008.

Variable	Total Count of Innovations
Average	8.787
Variance	4,520.210
Standard deviation	67.232
Max Value	2,560
Min Value	0,000
Negative values	0,000
Positive Values	2,127
Zero values	3,146
Observations	5,273

Source: Calculations based on EDIT 2007-2008

According to the EDIT 2007-2008 survey, 40% of the firms reported, on average, 46,338 innovations, while 60% of the firms did not innovate at all. Table 2 shows that the total count of innovation is a discrete variable that contains non-negative values, with a distribution that describes a Poisson process[3] (see Figure 1).

The independent variables at the sectoral and regional level had the following treatment. The continuous variables between 2007 and 2008 were averaged and standardized (see Table 3). Most of the independent variables at the firm, sector, and regional levels are continuous (see Table A.1, for summary statistics). However, some variables are discrete, which in this case we included dummy variables in the model.

B. Models of Count Data

These regression models are for non-negative integer or counts, for instance, the dependent variable as count of innovations takes values $y = 0,1,2...$ without upper explicit limit (Winkelmann, 2008). For this type of data, the Poisson Regression Model (PRM) is the appropriate one. This model assumes, in this case, that innovation is an event and behaves as a Poisson process, which is a stochastic

[2] DANE defines radical innovations as new goods or services; incremental innovations as goods and services that are significantly improved and strategic innovations are new organizational methods applied to management and production processes.

[3] Winkelmann (2008) describes the Poisson process as a special event count in which a stochastic process is carried out. This stochastic process is the accumulation of random variables (in a probability space) at a certain period.

Figure 1.
Histogram of the Total Count of Innovations

This figure reports the total counts of innovation based on the Technological Development and Innovation Survey (EDIT) 2007-2008.

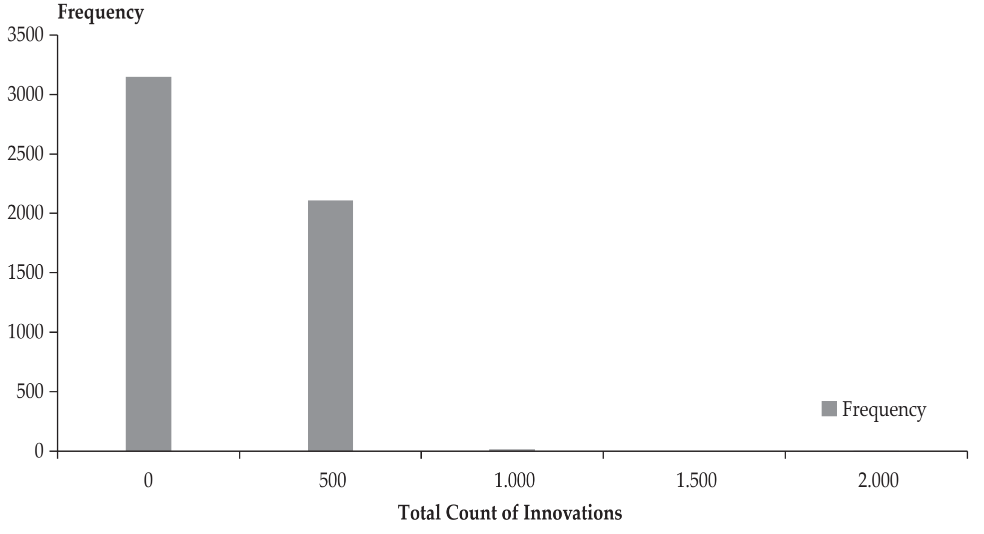

Table 3.
List of Independent Variables by Level

This table reports the description of innovation for firms (level 1) along with their sector (level 2) and regional headquarters (level 3).

Level	Variables	Description
1	Firms with foreign capital.	Companies with more than 25% of foreign capital will be considered a foreign company, this variable is binary where 1 are foreign companies and 0 otherwise. Source: EDIT 2007-2008. (Dummy)
	Size.	According to the number of employees, the average is taken between 2007-2008. Source: EDIT 2007-2008. (Standardized)
	Percentage of national private capital invested in R&D.	The total of own, foreign, and public resources divided by the total of private resources invested in R&D. Source: EDIT 2007-2008. (Standardized)
	Percentage of foreign private capital invested in R&D.	The companies that within their total capital have a percentage of private foreign capital invested in R&D. Source: EDIT 2007-2008. (Standardized)
	Internal Networks.	The companies' departments that participate in innovations developments, internal networks that the firm used over the total of networks (Int + Exter). Source: EDIT 2007-2008. (Standardized)
	External Networks.	External networks (clients, suppliers, universities, chambers of commerce, etc.) that the firm uses over the total of Int + Exter networks. Source: EDIT 2007-2008. (Standardized)
	Partner cooperation.	If the company had partner cooperation or not. Source: EDIT 2007-2008. (Dummy)
	Level of education: Bachelor, Master, and Ph.D.	Employees with Ph.D., Master, and Bachelor degrees are divided by the total employees. Source: EDIT 2007-2008. (Standardized)

Table 3.
List of Independent Variables by Level (Continued)

Level	Variables	Description
	Level of education: associate degree.	Employees with associate degrees are divided by total employees. Source: EDIT 2007-2008. (Standardized)
	Level of education: Bachelor, Master, and Ph.D. involve in R&D.	Employees with Ph.D., Master, and Bachelor degree involve with R&D divided by the total employees. Source: EDIT 2007-2008. (Standardized)
	Level of education: associate degree involves in R&D.	Employees with associate degrees involve in R&D divided by the total employees. Source: EDIT 2007-2008. (Standardized)
	Intellectual property and patents.	Summation of all types of intellectual property and patents that the company reported. Source: EDIT 2007-2008. (Standardized)
	Foreign R&D Financing.	The total of own, foreign, and public resources divided by the total of foreign resources invested in R&D. Source: EDIT 2007-2008. (Standardized)
2	Knowledge intensity: High.	According to the Gera and Masse classification (1996). Source: DANE Methodology Indicators of Industrial Competitiveness by Intensity of Knowledge. (Dummy)
	The intensity of knowledge: Low.	According to the Gera and Masse classification (1996). Source: DANE Methodology Indicators of Industrial Competitiveness by Intensity of Knowledge. (Dummy)
	Intensity of R&D.	Number of large companies that invested in R&D is divided by the number of companies that invest in R&D in the sector. Source: EDIT 2007-2008. (Standardized)
	Sectors with foreign capital.	The number of companies with foreign capital is divided by the number of companies in the sector. Source: EDIT 2007-2008. (Standardized)
	Commercial Opening Index of the sector.	It is the average of imports plus exports as a share of GDP for the years 2007-2008. Source: DANE, Competitiveness indicators, foreign trade. (Standardized)
3	Unemployment rate by department	Average unemployment rate by department (2007-2008) Source: DANE, labor market. (Standardized)
	Coverage in higher education.	Average of the higher education coverage rate in 2007 and 2008. Source: Ministry of Education, SNIES (National Information System of Higher Education) Database. (Standardized)
	Commercial opening index of the region.	It is the ratio between the average of imports plus exports and the GDP for the years 2007 and 2008. Source: DANE, foreign trade. (Standardized)
	National investment by region in R&D	Average of the R&D Investment by the department for the years 2007-2008. Source: OCYT. (Standardized)
	Distance to the Capital.	Kilometers away from the capital of each department of the region. Source: Google Earth. (Standardized)
	Research groups	Average of active research groups between 2007-2008. Source: Observatory of Science and Technology OCYT. (Standardized)

process that calculates the probability of the occurrence of an event in a certain period (Winkelmann, 2008).

As we see, in Table 2, the variance is larger than the mean and the dependent variable has 3146 zero values. These excessive zeros imply the sample violates the equi-dispersion assumption in the PRM, in which the mean is equal to the variance. To solve this problem, the Zero Inflated Poisson Model (ZIP Model) or Zero Inflated Negative Binomial Model (ZINB Model), which is an extension of PRM has been used in the literature (Lee *et al.*, 2006; Winkelmann, 2008). This number of zeros in the survey are common in developing countries. According to RICYT (2018), in countries like Argentina, Brazil, and Chile, less than 40% of the firms innovate. The Colombian case is not very much different from that, as approximately 60% of the companies did not innovate, according to the EDIT 2007-2008 survey.

C. Applying the Multi-level Zero-inflated Poisson ZIP Model

Following the literature (Hox *et al.*, 2017; Hur *et al.*, 2002; Lambert, 1992; Lee *et al.*, 2006; Long, 1997; Wang *et al.*, 2011), this paper uses multilevel models with mixed-effects that involve count data, since this is the nature of the dependent variable. To run a multi-level model with a high number of zeros, Long (1997) suggests to classified these zeros into two groups. First, we have structural zeros with a π_i probability, which represents companies that always have zero innovation counts, given that these companies structurally do not comply with the technological capabilities to innovate. Second, circumstantial zeros with $(1-\pi_i)$ probability may occur because even though companies comply with the technological capabilities to develop innovations, they do not achieve their innovation goals at the end of the period, or because innovation was still underway at the time of the survey.

Following Lambert (1992), the ZIP technique can run a Poisson and a logit model simultaneously. The Poisson model allows us to find not only the circumstantial zeros but also the arrival rate or innovation count, while the logit model estimates the probability when firms do not innovate. Traditionally, this type of model can be generated from an approximation of a generalized linear mixed model by the maximum likelihood technique (see Wang *et al.*, 2011; Hur *et al.*, 2002; Lee *et al.*, 2006).

In multilevel models, the variables are expressed in a linear system of equations as below[4].

$$y_{ijk} = \beta_{0jk} + \alpha_1 x_{1jk} + \beta_1 Z_{1jk} + e_{ijk} \tag{1}$$

$$\beta_{0jk} = \gamma_{00k} + \gamma_{01} W_{1jk} + u_{0jk} \tag{2}$$

$$\gamma_{00k} = \eta_{000} + \eta_{011} G_{1k} + v_{00k} \tag{3}$$

where y_{ijk} represents the count of innovation for firm *i* (level 1) operating in sector *j* (level 2) and headquartered in region *k* (level 3). Z_{1jk} is a vector of variables at the firm level, β_{0jk} represents the intercept in the first level that changes according to the sector's determinants W_{1jk}, and γ_{00k} is the intercept in the second level, which varies according to the regional determinants G_{1k}. Integrating Equations (1) to (3) gives us:

[4] Usually, multilevel models have cross-level interaction effects. To have a deeper understanding of these effects, we refer to Gelman and Hill (2007) and Hox *et al.* (2017).

$$y_{ijk} = \eta_{00} + \eta_{01}G_{1k} + \gamma_{01}W_{1jk} + \alpha_1 x_{1jk} + \beta_1 Z + u_{0jk} + v_{00k} + e_{ijk} \quad (4)$$

This model is similar to an ordinary linear regression model with fixed effects $\alpha_1, \gamma_{00k}, \gamma_{01}, \eta_{00}, \eta_{01}$ and random coefficients $u_{0jk}, v_{00k}, e_{ijk}$.

The maximum likelihood (ML) method is commonly used to estimate multilevel models. The ML technique is generally robust and gives estimates that are asymptotically efficient and consistent (Hox *et al.*, 2017). The advantages and limitations when using multilevel models are generally associated with the quality and the structure of the data. As the innovation process happens at different levels, there are some unobserved conditions by the model which is also known as unobserved heterogeneity. The differences between firms, sectors, and regions are unknown by the model. Multilevel models with random parameters and mixed effects assume, however, that the unobserved individual-specific heterogeneity is unrelated to the explanatory-variable vector. By considering the hierarchical structure of the data, multilevel models prevent type I errors and aggregation biases, which consist of making statistical inferences at the individual level from aggregate data (Wang *et al.*, 2011).

Table 4.
Results of the Multi-level Zero Inflated Poisson ZIP Model

This table reports the results using the multi-level Zero Inflated Poisson ZIP model with and without Open Economy Variables (OEV) for the full sample. Dependent Variable is total count of innovation based on the Technological Development and Innovation Survey (EDIT) 2007-2008. The ISIC level belongs to the sector level and CD to the regional level. Standard errors robust to heteroscedasticity are in the parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Variables	**Poisson without OEV**	**ISIC**	**CD**	**Poisson with OEV**	**ISIC**	**CD**
Observations	5,273	5,273	5,273	5,273	5,273	5,273
Number of Groups		64	32		64	32
Constant	2.292*** (0.075)	0.991*** (0.113)	1.024*** (0.037)	2.295*** (0.105)	0.980*** (0.115)	1.023*** (0.037)
Firms with foreign capital				-0.180*** (0.026)		
Foreign R&D Financing				0.028*** (0.002)		
Percentage of foreign private capital invested in R&D				0.0134*** (0.000)		
0Size	0.104*** (0.002)			0.112*** (0.002)		
Percentage of national private capital invested in R&D	-0.087*** (0.004)			0.151*** (0.020)		
Internal Networks	0.065*** (0.007)			0.060*** (0.007)		
External Networks	0.022*** (0.006)			0.018*** (0.006)		
Partner cooperation	0.095*** (0.011)			0.100*** (0.011)		

Table 4.
Results of the Multi-level Zero Inflated Poisson ZIP Model (Continued)

Variables	Poisson without OEV	ISIC	CD	Poisson with OEV	ISIC	CD
Level of education: Bachelor. Master and PhD	0.132*** (0.005)			0.128*** (0.005)		
Level of education: associate degree	0.022*** (0.006)			0.031*** (0.006)		
Level of education: Bachelor. Master and PhD involve in R&D	0.006 (0.004)			0.007* (0.004)		
Level of education: associate degree involve in R&D	-0.078*** (0.005)			-0.080*** (0.005)		
Intellectual property and patents	0.014*** (0.003)			0.029*** (0.003)		
Knowledge intensity: High	0.325*** (0.046)			0.425*** (0.066)		
Intensity of knowledge: Low	-0.009 (0.230)			-0.012 (0.232)		
Intensity of R&D	0.227** (0.106)			0.254** (0.117)		
Sectors with foreign capital				-0.107 (0.103)		
Commercial Opening Index of the sector				-0.062 (0.068)		
Unemployment rate by department	0.514*** (0.084)			0.700*** (0.108)		
Coverage in higher education	0.218*** (0.064)			0.348*** (0.069)		
Commercial opening index of the region				0.222*** (0.062)		
National investment by region in R&D	0.738*** (0.067)			0.742*** (0.065)		
Distance to the Capital	-0.282*** (0.050)			-0.284*** (0.044)		
Research groups	-0.912*** (0.092)			-0.978*** (0.090)		
Log-Likelihood Empty Model		-61,256.359			-61,2563.59	
Log-Likelihood Full Model		-57,301.352			-57,148.843	
Pseudo R2		6.456%			6.705%	

IV. EMPIRICAL FINDINGS

Two scenarios have been used to test both hypotheses. In the first scenario, the economy is closed and therefore the model includes ten variables at the *firm level*, three at the *sectoral level*, and five at the *regional level*. *In the second scenario*, there is an open economy and therefore the model includes the same variables as the first model plus the OEV variables: three OEV at the *firm level*, two at the *sectoral level*, and one at the *regional level* were added to the model.

After running the first model under the assumption of a closed economy, we can identify in Table 4 that nine out of the ten firm-level variables are significant. We find that the percentage of national private capital invested in R&D and personnel with an associate degree that involves R&D are negatively associated with innovative productivity of firms. In addition, at the second level, two out of three variables are significant. The sectors with high R&D and knowledge intensities have a positive influence on the innovative performance of industrial manufacturing firms. Previous studies, such as Savrul and Incekara (2015) and Zawislak *et al.* (2018), have also confirmed that sectors with high R&D and knowledge intensities have a positive effect on innovation. Finally, at the third level, all five variables are significant. Two of these variables, *viz.*, distance to the capital city and research groups, have negative effects on innovation. First, Concilio *et al.* (2019), Florida *et al.* (2017), and Rammer *et al.* (2020) have explained that capital cities are hubs of science and technology. Hence, considering the results, companies that are more distant from capital cities tend to innovate less. Second, in Colombia, R&D activities are supported by research groups and universities. The latest report of the Colombian Ministry of Science, Technology, and Innovation (2020) shows that, on average, only 5% of the research groups are involved in high intensive technology sectors, while 37% of the research groups are involved in social sciences and education. Therefore, the interpretation of the negative effect of research groups on innovation performance of manufacturing firms reflects, to some extent, the lack of technology-oriented research groups.

After running the second model with the assumption of the open economy, firm-level OEV in Table 4 is significant. However, from the multilevel perspective, some variables have unexpected coefficient signs. For example, companies with foreign capital have a lower total count of innovation by exp(-0.180)=0.835 times the expected number of companies with no foreign capital. We expected that companies with more foreign capital would have a higher innovation count compared with other firms. These interpretations can change according to the country's FDI agenda. According to the Colombian Central Bank, during the period 2007-2008, the mining and oil extraction sector captured almost 50% of the total FDI, while the manufacturing industry only attracted, on average, 16.5% of the total FDI during the same period. Even though firms demand FDI, this investment does not go to the innovative sectors of the manufacturing industry, thereby hurting the innovation count. Blanco-Estévez (2015) concluded that Latin American firms invest only 0.60 US dollars per 100.000 US dollars in income in R&D, while emerging countries in Asia invest 17 US dollars.

Additionally, if the *percentage of private foreign capital invested in R&D* was to increase by one percent, the expected number of innovations would increase by a factor of exp(0.0134)=1.0134. According to Morero (2017), in developing countries, local firms are not getting enough R&D investment from the local private sector. Hence, local firms will demand foreign R&D investment. Holding the rest of the variables constant, if the firm increases its *proportion of foreign capital* by one percent then the count of innovations will increase by a factor of exp(0.0283)=1.028.

The Schumpeterian hypothesis of size (Schumpeter, 1934; 1943) is proven right in both scenarios. Control variables, such as networks, partner cooperation, patents, and intellectual property rights, maintain a significant and positive relationship, complying with previous studies, such as Baker *et al.* (2017), Balachandran and Hernandez (2018), Galaso and Kovářík (2018).

In terms of education, at the firm level, the model includes four variables. While holding the rest of the variables constant, if a firm hires one additional employee with a bachelor, master, and Ph.D. degree, it will increase its innovations by a factor of exp(0.132)=1.141 and exp(0.128)=1.136 under closed and open economy, respectively. If a firm hires one additional employee with an associate degree, it will increase innovations by a factor of exp(0.0221)=1.022 and exp(0.0319)=1.032 under closed and open economy, respectively. Furthermore, firms that hire one more employee with a bachelor, master, and Ph.D. degree in the R&D department under the open economy scenario will increase their innovation by a factor of exp(0.00778)=1.007. Conversely, companies that hire one more employee with an associate degree in the R&D department will decrease their innovation by a factor of exp(-0.0789)=0.924 and exp(-0.0808)=0.923 under the closed and open economy scenarios, respectively. If we look closer at the EDIT 2007-2008 bulletin, only 0.1% of the personnel employed in the industry reached doctoral level, 0.4% had a master degree, 12% had bachelor degree, and 9.1% had an associate degree; not to mention the 31,4% of the companies that could not access skilled personnel.

At the sectoral level, only two variables are significant. Sectors with high knowledge intensity have positive effects in both scenarios (i.e., closed and open economies). The intensity of R&D also generates a positive effect on the innovation counts. Nevertheless, the model does not show enough evidence to determine the impact of the OEV in the sectors.

At the regional level, all variables are significant. Control variables, such as distance to the capital city and the number of active research groups have a negative impact on innovation, by decreasing the propensity to innovate. The unemployment rate, coverage in higher education, the commercial opening index, and the national investment in R&D have a positive relationship with innovation.

Education plays an important role in the process of innovation. Keeping the rest of the variables unchanged in the model, if the coverage of higher education in the region increases by one percent, the firms will increase the count of innovation by a factor of exp(0.218)=1.243 and exp(0.348)=1.416 under closed and open economy, respectively.

When the commercial opening index at the regional level increases by one percent, the firms will increase their innovation count by a factor of exp(0.222)=1.248. Even though the commercial opening index of the region has a positive effect on innovation, it is important to mention that, in Colombia, high technology represented 19.8% of total imports, while medium technology reaches 35.7% of total imports during the period 2007-2008. On the other hand, DANE showed that high technology exports in Colombia represented only 2.3% of the total exports, which is low compared with the Latin America average of 11%. The Colombian economy is highly dependent. on coal and oil, as commodities represent almost half of the total exports.

Table A.2 in the appendix is used as robustness checks and shows the results for the three types of innovations. As seen, OEV still has a significant relationship with innovation performance. Our firm-level variables of interest hold significance even after controlling for OEV variables (see Table A.2). We have also run the logit estimation for robustness and reported the estimates in Table A.3. Looking at these robustness checks in Table A.2 and Table A.3, we conclude that our findings are rather robust to alternative modeling strategies.

V. CONCLUSIONS

This study examines the roles of education and open economy variables (or OEV) in the innovative performance of Colombian manufacturing firms. Consistent with our expectations, we find that education is fundamental to innovation performance and development. The econometric model at the firm level shows a positive relationship between innovation and higher education, implying that it is important to strengthen the link between universities and industry. Promoting university–industry collaboration will improve technological capabilities, the acquisition and the adoption of new knowledge and technology, R&D activities, and the development of new products. All these advantages can be obtained, if governments apply the best policy agenda that stimulates university–industry linkage.

Even though there is a positive relationship between coverage in higher education and innovation performance of firms, the quality of education and the enrolment rate in Colombia needs to catch up with OECD country members. Despite the lack of evidence at the sectoral level, our model with OEV variables shows that these variables are positively related to innovation count at both the regional and firm levels. This confirms that trade and FDI have a positive impact on innovation through knowledge and technology transfer to local firms.

Furthermore, our findings are supportive of our hypothesis that the innovative performance of firms is significantly related to open economy variables. Even though there is a significant relationship between innovation and the open economy variables, the interpretations may bring different insights. According to the results, we can conclude that even though firms have a percentage of FDI, it does not necessarily mean that FDI positively influences innovation unless firms allocate a fraction of it to R&D activities.

At the regional level, we conclude that foreign trade has a positive impact on the innovation performance of firms. This positive impact is related to technology transfer. Despite the positive impact of foreign trade on innovation, Colombia must strengthen its technological capabilities to boost high technology exports.

After analyzing the education and foreign trade variables, we conclude that Colombia has a fragmented innovation system with a weak institutional structure, and low interaction between policymakers, industry, universities, research centers, and other components and building blocks of the system. Given the complexity of the behavior of innovation systems in emerging economies, Colombia needs to align its economic development agenda by promoting science, technology, and innovation policies without leaving out the environmental factors, the population's welfare, and development. Following the same research line of innovation systems in emerging economies, different research questions for future studies are also arising. For example, how can we measure university–industry cooperation in Colombia? How can we evaluate the technological capabilities of the Colombian system? What is the performance of innovation in other sectors such as agriculture and services? What are the impacts of digitalization on innovation performance?

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APPENDIX

Table A.1.
Summary Statistics for Independent Variables

This table reports the summary statistics for independent variables We refer to Table 3 for the description of the variables.

Variables	Size	Percentage of National Private Capital Invested in R&D	Percentage of Foreign Private Capital Invested in R&D	Internal Networks
Observations	5,273	5,273	5,273	5,273
min	1	0	0	0
max	7,640	46,357	46,966	1
range	7,639	46,357	46,966	1
sum	598,001	1135151.630	411697.010	1553.048
median	34	100	0	0
mean	113.408	215.276	78.076	0.295
var	84599.343	4710010.107	3189563.928	0.135
std.dev	290.860	2170.256	1785.935	0.368
Variables	**External Networks**	**Partner Cooperation**	**Level of Education: Bachelor, Master and PhD**	**Level of Education: Association Degree**
Observations	5,273	5,273	5,273	5,273
min	0	0	0	0
max	1	1	1	1
range	1	1	1	1
sum	854.95	1,090	610.24	427.75
median	0	0	0.08	0.03
mean	0.16	0.21	0.12	0.08
var	0.06	0.16	0.02	0.02
std.dev	0.25	0.40	0.12	0.14
Variables	**Level of Education: Bachelor, Master, and PhD involve in R&D**	**Level of Education: Association Degree Involve in R&D**	**Intellectual Property and Patents**	**Foreign R&D Financing**
Observations	5,273	5,273	5,273	5,273
min	0	0	0	0
max	0.625	0.750	90	1
range	0.625	0.750	90	1
sum	71.207	26.907	1,123	12.304
median	0	0	0	0
mean	0.014	0.005	0.213	0
var	0	0	6.231	0
std.dev	0.042	0.027	2.496	0.037

Table A.1.
Summary Statistics for Independent Variables (Continued)

Variables	Intensity of R&D	Sectors with Foreign Capital	Commercial Opening Index of the Sector	Unemployment Rate by Department
Observations	5,273	5,273	5,273	5,273
min	0	0	0	0
max	1	1	811,479,188,148,951	0.157
range	1	1	811,479,188,148,951	0.157
sum	3795	384	3.27E+17	578.016
median	0.76	0.07	0.375	0.104
mean	0.72	0.07	62,066,726,263,379	0.110
var	0.04	0.00	3.49E+28	0.000
std.dev	0.20	0.06	186,828,935,906,393	0.010

Variables	Coverage in Higher Education	Distance to the Capital	National Investment by Region in R&D	Commercial Opening Index of the Region
Observations	5,273	5,273	5,273	5,273
min	0.07	0	0	0.005
max	0.657	1,302	0.539	11,647,776,947,552
range	0.592	1,302	0.539	11,647,776,947,551.9
sum	2,347	1,803,092	1410.691	34,943,330,844,239
median	0.363	439	0.239	0.293
mean	0.445	341.948	0.268	6,626,840,668.356
var	0.031	127,770	0.052	7.72E+22
std.dev	0.175	357.449	0.228	277,774,512,396.426

Variables	Research Groups
Observations	5,273
min	0
max	44,341
range	44,341
sum	7,283,707
median	502.500
mean	1,381.321
var	27,002,138.491
std.dev	5,196.358

Table A.2.
Results of the Multi-level Zero Inflated Poisson Model for Innovation Types

This table reports the results of the multi-level Zero Inflated Poisson model for different innovation types: Radical Innovations, Incremental Innovations and Strategic Innovations. The dependent Variable is the total count of innovation for each type of innovation and is retrieved from the Technological Development and Innovation Survey (EDIT) 2007-2008. The ISIC level belongs to the sector level and CD to the regional level. Standard errors robust to heteroscedasticity are in the parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Variables	Radical Innovations with OEV	ISIC	CD	Incremental Innovations with OEV	ISIC	CD	Strategic Innovations with OEV	ISIC	CD
Observations	5.273	5.273	5.273	5.273	5.273	5.273	5.273	5.273	5.273
Number of Groups		64	32		64	32		64	32
Constant	1.150*** (0.234)	-1.283*** (0.389)	0.123** (0.0479)	1.222*** (0.235)	-1.479** (0.602)	0.123** (0.0501)	0.529*** (0.194)	-1.406*** (0.463)	-0.181*** (0.0527)
Firms with foreign capital	0.0400 (0.0384)			-0.584*** (0.0586)			0.118* (0.0616)		
Percentage of foreign private capital invested in R&D	0.0165*** (0.00140)			0.0147*** (0.00113)			-0.00944*** (0.00124)		
Foreign R&D Financing	0.0439*** (0.0027)			-0.0484*** (0.00957)			0.00796 (0.00768)		
Size	0.0954*** (0.0040)			0.101*** (0.00602)			0.252*** (0.00730)		
Percentage of national private capital invested in R&D	0.261*** (0.0300)			0.0316 (0.0243)			-0.154*** (0.0240)		
Internal Networks	0.136*** (0.0109)			0.158*** (0.0205)			0.230*** (0.0236)		
External Networks	-0.0203** (0.0098)			-0.0606*** (0.0165)			0.107*** (0.0188)		
Partner cooperation	-0.243*** (0.0164)			0.0727*** (0.0235)			0.0323 (0.0285)		

Table A.2.
Results of the Multi-level Zero Inflated Poisson Model for Innovation Types (Continued)

Variables	Radical Innovations with OEV	ISIC	CD	Incremental Innovations with OEV	ISIC	CD	Strategic Innovations with OEV	ISIC	CD
Level of education: Bachelor, Master and PhD	0.0929*** (0.00855)			0.290*** (0.0117)			0.0639*** (0.0157)		
Level of education: associate degree	0.189*** (0.0085)			-0.0293** (0.0146)			-0.0113 (0.0173)		
Level of education: Bachelor, Master and Ph.D. involve in R&D	0.0302*** (0.00596)			0.00143 (0.00865)			-0.00700 (0.0106)		
Level of education: associate degree involve in R&D	-0.306*** (0.0107)			-0.119*** (0.00991)			0.0503*** (0.00945)		
Intellectual property and patents	0.0109** (0.00549)			0.0186*** (0.00601)			0.0103 (0.00845)		
Knowledge intensity: High	-0.0276 (0.207)			-0.146 (0.208)			-0.335* (0.171)		
Intensity of knowledge: Low	0.0297 (0.255)			-0.0962 (0.280)			-0.176 (0.211)		
Intensity of R&D	0.0472 (0.128)			0.130 (0.139)			-0.0557 (0.105)		
Sectors with foreign capital	0.00602 (0.142)			0.0199 (0.143)			0.0350 (0.109)		
Commercial Opening Index of the sector	0.115 (0.0743)			0.0319 (0.0707)			0.0325 (0.0574)		
Unemployment rate by department	1.464*** (0.325)			0.434 (0.335)			0.328 (0.274)		

Table A.2.
Results of the Multi-level Zero Inflated Poisson Model for Innovation Types (Continued)

Variables	Radical Innovations with OEV	ISIC	CD	Incremental Innovations with OEV	ISIC	CD	Strategic Innovations with OEV	ISIC	CD
Coverage in higher education	-0.205 (0.161)			-0.0571 (0.163)			-0.183* (0.107)		
Commercial opening index of the region	-0.194 (0.148)			-0.0834 (0.149)			-0.0595 (0.107)		
National investment by region in R&D	0.321 (0.248)			0.347 (0.252)			0.0159 (0.184)		
Distance to the Capital	-0.0490 (0.0860)			-0.150* (0.0910)			0.0394 (0.0667)		
Research groups	-0.100 (0.303)			-0.232 (0.308)			0.132 (0.214)		
LL Empty Model		-34926.434			-14596.326			-7965.7485	
LL Full Model		-32800.719			-13199.583			-7097.2175	
Pseudo R2		6.086%			9.569%			10.903%	

Table A.3.
Results of the Logit model

This table reports the results using the logit model with and without Open Economy Variables (OEV) for the full sample. Dependent Variable is total count of innovation based on the Technological Development and Innovation Survey (EDIT) 2007-2008. The ISIC level belongs to the sector level and CD to the regional level. Standard errors robust to heteroscedasticity are in the parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Variables	Logit without OEV	ISIC	CD	Logit with OEV	ISIC	CD
Observations	5,273	5,273	5,273	5,273	5,273	5,273
Number of Groups		64	32		64	32
Constant	0.602*** (0.208)	-1.596*** (0.283)	-14.180 (161.228)	0.450* (0.259)	-1.642*** (0.297)	-21.880 (340.000)
Firms with foreign capital				-0.338 (0.267)		
Percentage of foreign private capital invested in R&D				-0,007 (0.006)		
Foreign R&D Financing				-0.127 (0.092)		
Size	-0.414*** (0.067)			-0.408*** (0.067)		
Percentage of national private capital invested in R&D	0,010 (0.047)			-0,069 (0.118)		
Internal Networks	-1.421*** (0.0454)			-1.422*** (0.045)		
External Networks	-0.698*** (0.042)			-0.694*** (0.042)		
Partner cooperation	-0.713*** (0.118)			-0.705*** (0.118)		
Level of education: Bachelor, Master and PhD	0.157*** (0.053)			0.155*** (0.053)		
Level of education: associate degree	0,0544 (0.048)			0,0534 (0.048)		
Level of education: Bachelor, Master and PhD involve in R&D	-0.837*** (0.0905)			-0.834*** (0.0906)		
Level of education: associate degree involve in R&D	-0.170*** (0.0537)			-0.170*** (0.0539)		
Intellectual property and patents	-0.118 (0.0874)			-0.120 (0.0869)		
Knowledge intensity: High	-0,0463 (0.144)			-0,0116 (0.176)		
Intensity of knowledge: Low	0.103 (0.184)			0,0932 (0.183)		
Intensity of R&D	-0,0252 (0.102)			-0,0206 (0.107)		
Sectors with foreign capital				-0,045 (0.163)		

Table A.3.
Results of the Logit model (Contiued)

Variables	Logit without OEV	ISIC	CD	Logit with OEV	ISIC	CD
Commercial Opening Index of the sector				-0,019 (0.051)		
Unemployment rate by department	-0.251 (0.307)			-0.232 (0.307)		
Coverage in higher education	0.377*** (0.115)			0.508*** (0.131)		
Commercial opening index of the region				0.295** (0.136)		
National investment by region in R&D	0.142 (0.153)			0.186 (0.155)		
Distance to the Capital	-0,0952 (0.0778)			-0.155* (0.0823)		
Research groups	-0.289 (0.189)			-0.421** (0.198)		
LL Empty Model		-3515.3311			-3515.3311	
LL Full Model		-1718.6624			-1713.5771	
Pseudo R2		51.110%			51.254%	

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