Relationship Of Financial Performance And Technical Efficiency With Innovation And Investment In R+D In Microenterprises In The Industrial Sector In Colombia

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Abstract. Colombia is a country where SMEs make up the majority of the business fabric, generating employment and contributing significantly to GDP, although they face limitations in innovation and technological adoption that affect their productivity and profitability. In this context, variables such as research and development (R+D) and innovation are recognized as strategic elements to strengthen business performance and economic growth. However, gaps in technological capabilities, access to resources, and knowledge networks continue to limit the productive sector. Therefore, this study seeks to empirically analyze the relationship between innovation, R+D, total factor productivity (TFP) and return on assets (ROA) in the Colombian industrial sector, using data from the EAM and EDIT of DANE (2013–2022) and the Levinsohn and Petrin method to estimate these effects more accurately according to firm size. The findings will make it possible to identify differential policies that promote innovation effectively, adapted to the characteristics of each type of company.
Keywords: Innovation, Research and Development (R+D), Total Factor Productivity (TFP), Return on Assets (ROA), SMEs, Colombian industrial sector.

1. INTRODUCTION

Colombia is a nation characterized by a predominance of micro, small, and medium-sized enterprises (MSMEs). These enterprises constitute the vast majority of all formal enterprises, accounting for 99.5% of the total. They are responsible for generating approximately 79% of employment opportunities and contributing between 35 and 40% of the formal GDP (BBVAResearch, 2024). In this context, it is relevant to consider that, for several decades, variables such as research and development (R+D) have been identified as key elements to improve business performance and promote economic growth. In this vein, it is imperative to comprehend the correlation between these variables and productivity and profitability. This understanding is crucial for the formulation of strategies that will guide the nation's productive development. This is particularly salient in Colombia, where low levels of innovation and technological adoption have repeatedly constrained business productivity (Departamento Nacional de Planeación-DNP, 2016).
It is imperative to acknowledge that the discrepancies in the adoption and generation of knowledge within the nation have counteracted the endeavors undertaken to fortify the

technological capabilities of the productive apparatus. A dearth of resources, restricted access to knowledge networks, and limitations in organizational capacities translate into structural constraints for the business sector (Demuner et al., 2019). This research utilizes a particular examination of the Colombian industrial sector, with a concentration on firm size, to generate empirical evidence regarding the impact of innovation, research, and development on total factor productivity (TFP) and return on assets (ROA).

To this end, data from the Annual Manufacturing Survey (EAM) and the Survey of Development and Technological Innovation (EDIT), prepared by DANE and corresponding to the period 2013–2022, are utilized. The methodology employed by Levinsohn & Petrin (2003) involves the implementation of analytical techniques that facilitate the management of endogeneity and selection biases. These techniques are further augmented by the utilization of fixed-effect models, which are designed to accurately discern unobservable variations among signatures. This methodology is expected to identify the effect of innovation, research, and development on the operational and financial results of companies with greater precision.

The results of this research are summarized as follows: in the case of medium and large companies, it is found that investment in R+D has a positive effect on productivity. For micro and small companies, however, this impact is reduced when unobserved variables specific to each firm are controlled. Conversely, for large companies, it is evident that innovation contributes to increased productivity and that R&D has a positive effect on ROA. However, a solid relationship is not identified for other business sizes. It has been observed that, irrespective of firm size, the export and import of inputs have been demonstrated to be a reliable predictor of increased productivity.

These findings indicate the necessity of formulating diversified policies to ensure that innovation yields tangible benefits commensurate with the distinctive characteristics of each company type. For instance, small enterprises require capacity building, access to knowledge, and collaborative networks, as well as financial support. Conversely, large companies benefit from incentives aimed at promoting strategic alliances, connections with broader technological ecosystems, and applied innovation. It is important to acknowledge that, in both scenarios, the continuity of public policies and the stability of institutions contribute to a more reliable environment. This reliability is a fundamental element in sustaining and consolidating the effects of innovation over time.

The article is structured as follows: the second section reviews the main theoretical approaches and previous studies on innovation, productivity, and financial performance. The third section of the text presents a detailed description of the data and variables that were utilized in the study. The fourth section delves into the empirical strategy employed in the research, providing a comprehensive explanation of the methodological approach. The fifth section is devoted to the presentation of the primary results and their subsequent discussion. The sixth section is reserved for the articulation of conclusions and the proposition of implications for the design of public policy.

2. LITERATURE REVIEW

A literature review was conducted to establish a solid basis on the current state of research regarding the relationship between innovation, investment in research and development (R+D), total factor productivity (TFP), and financial performance, measured through return on assets (ROA), in microenterprises in the Colombian industrial sector. This analysis is carried out in a systematic and critical manner, which allows for the identification of the main theories, empirical findings, methodologies used, and topics that require further in-depth study in this area. In this manner, it endeavors to establish a substantial theoretical framework for the research, circumventing redundancies and meticulously guiding the methodological design of the study with enhanced precision.

Microenterprises constitute a substantial segment of the Colombian business landscape, performing a pivotal role in employment generation and national economic growth. However, they encounter various challenges related to resource access, innovation, and the adoption of new technologies. Given Colombia's status as an emerging economy, it is imperative to examine these factors to formulate effective public policies and business strategies that enhance the competitiveness and sustainability of this business sector. In this sense, understanding how innovation and investment in R+D affect the technical efficiency and financial performance of microenterprises becomes a key element to guide decisions in terms of productive development.

2.1. The Theoretical Foundations

A multitude of studies have examined the correlation between innovation, investment in research and development (R+D), productivity, and financial performance. These studies have identified that this relationship is predicated on divergent theoretical approaches related to economic growth and strategic business management. In this sense, the research by Romer (1990) provides an endogenous growth approach, a theory that maintains that sustained economic growth depends on engines such as knowledge and ideas, which are not rival goods and can be shared, generating increasing returns. According to this approach, innovation is an endogenous result that arises from the strategic decisions of individuals. These strategic decisions can be influenced by the accumulation of human capital and investment in R+D.

Furthermore, Aghion & Howitt (1992) proposed a growth model predicated on the notion of "creative destruction," which posits that the most innovative companies enhance aggregate productivity and displace their competitors in the market. This process suggests that companies must continuously endeavor to invest in innovation to sustain or enhance their competitive standing, while concurrently contributing to the overall economic growth. Consequently, innovation driven by technological change has emerged as a critical factor for ensuring sustained economic growth over the long term.

The approach presented by Barney (1991) is predicated on the theory of resources and capabilities within business management, positing that companies can achieve sustainable competitive advantages if they possess scarce, valuable, non-substitutable, and difficult to imitate resources. In this sense, organizational knowledge, technological capacity, and innovative culture are considered key strategic assets for competitiveness. In response, they have developed the concept of dynamic capabilities, which is part of an environment characterized by rapid changes. In such an environment, companies require skills to integrate, build, and reconfigure internal and external competencies. These capabilities are manifested through innovation, since in order to develop new products, it is essential to learn, adapt, and transform organizational structures continuously (Teece et al., 1997).

The contemporary approaches under discussion have their origins in the contributions of Schumpeter, who termed the process "creative destruction" (Schumpeter, 1942). This term refers to the process by which innovation constitutes the core of economic development. This process entails the substitution of obsolescent technologies and the conversion of industrial structures, resulting in the generation of novel combinations of factors, whether in the form of products, processes, or organizational methodologies. In this sense, innovation has been shown to positively impact economic growth and modify the structure of markets, generating opportunities for some companies while displacing others. Consequently, within the business realm, firms that successfully innovate are often positioned for a competitive advantage in the market. This, in turn, enables them to enhance their production efficiency and profitability

It has been demonstrated that productive efficiency can be explained by essential factors, including knowledge and technology. The implementation of suitable technologies and the effective management of internal knowledge have been demonstrated to engender substantial benefits, including enhanced resource allocation, process optimization, and an augmentation in total factor productivity (TFP). In this sense, they emphasize that competition in markets serves as a catalyst for innovation and demonstrate that the productivity of companies is directly influenced by knowledge management practices and the utilization of digital technologies. Consequently, although technical efficiency is contingent on physical capital and labor, it is imperative that these inputs be fortified through knowledge and technological innovation (Bloom, Sadun, & Reenen, 2012).

2.2. Innovation and R+D as determinants of Total Factor Productivity (TFP) and ROA

Total factor productivity (TFP) is a measure of the efficiency with which an economy or firm converts inputs, such as labor and capital, into products or services. According to Zymek (2024), the ability of an economy to generate income from resources utilized in production is also measured. Moreover, this measure differentiates itself from other productivity metrics in that it not only considers the increase in the amount of inputs employed, but also captures the effects of technological innovation, improvements in management, and economies of scale.

A seminal study by Olley and Pakes (1996) employed an econometric method to estimate TFP at the firm level. This method utilized investment as an instrumental variable to control endogeneity in the estimation of production functions. Consequently, Levinsohn and Petrin (2003) advanced a novel approach that is well-suited for contexts where investments may be null or unobservable, employing intermediate inputs as control variables. Conversely, the methodology proves particularly pertinent for manufacturing sectors exhibiting high heterogeneity. It enables the estimation of TFP, taking into account product differentiation and the presence of multi-product companies. This research by Loecker (2011) has contributed to the development of econometric methods that address the problems of concurrency and selection bias, allowing more accurate estimates of TFP in different business contexts. Research conducted by Griffith et al. (2006) corroborates the positive relationship between TFP growth, innovation, and investment in R&D. The findings indicate that companies that innovate and invest in these factors experience substantial increases in productivity. However, the nature of this relationship is subject to influence by the institutional and economic context of each nation. In this sense, BID (2010) underscores the pivotal role of institutions, infrastructure, and human capital in contexts where endeavors are made to invest in

R+D, yet the regions encounter structural impediments that curtail the prospective impact of such investments on productivity.

Improvements in management and the adoption of appropriate technologies can be advantageous for microenterprises. In this regard, the study by Salas et al. (2023) analyzes the relationship between innovation, R+D, and TFP in industrial microenterprises, and suggests that investment in innovation can significantly boost their competitiveness and efficiency. Conversely, numerous studies have examined the correlation between financial performance, as gauged by ROA, and innovation and investment in R+D. In the case of Colombia, Salas et al. (2023) found that small and medium-sized manufacturing companies that invest in innovation have superior financial results. Conversely, they identified a positive correlation between business performance and innovation, as well as learning orientation. Taken together, these findings suggest that companies can improve their profitability by investing in R+D and adopting innovative practices, which reinforces the relevance of innovation as a strategic element for strengthening competitiveness and sustainability in the Colombian industrial sector (Flores et al., 2019).

However, the size of the firm has been demonstrated to influence the impact that innovation can have on ROA. According to Albarracín & Lema (2012), the literature, small and medium-sized enterprises (SMEs) can benefit from the agility and flexibility that characterized the aforementioned entities. However, significant challenges have been identified that SMEs face when implementing innovation processes, primarily due to limited financial and human resources(Salas et al., 2023). Large companies have been shown to enhance their financial performance through investment in R+D by taking advantage of greater resources and economies of scale, thereby consolidating innovation strategies over time

The returns on investment in research and development (R+D) and innovation are typically not immediate.   Sanabria and Scavone (2019) assert that it is generally accepted that the aforementioned benefits typically manifest over the medium and long term. This is due to the fact that alterations in processes, in addition to the implementation and development of novel technologies, necessitate a temporal period to become firmly established. Consequently, in order to assess the influence of innovation strategies on return on assets (ROA), it is imperative that firms consider a longer time horizon when conducting impact assessments of such strategies.

2.3. Description of the data

The present research utilizes microdata from two structural statistical operations carried out by the National Administrative Department of Statistics (DANE): the Annual Manufacturing Survey (EAM) and the Survey of Development and Technological Innovation (EDIT). The two aforementioned surveys have gained prominence in the analysis of business performance in Colombia due to their extensive national coverage, methodological rigor, and temporal continuity. This methodological quality enables the generation of robust and comparable estimates over time, facilitating the study of the relationship between innovation, R&D, and the performance of companies in the industrial sector.

The EAM furnishes exhaustive information regarding the economic and productive characteristics of industrial establishments in Colombia. This includes variables such as sales, assets, employment, consumption of raw materials, and exports, among others.

Conversely, EDIT places emphasis on aspects pertaining to technological innovation, the utilization of information and communication technologies (ICT), and investment in research and development (R+D) activities. The amalgamation of these sources enables a comprehensive characterization of the productive performance and innovation strategies of industrial companies, thereby facilitating the analysis of the effect of innovation and investment in R&D on productivity and financial performance.

The period of analysis encompasses the years 2013 to 2020, during which the comparability of the variables employed is ensured, as well as the validity of the definitions and statistical classifications applied by DANE, such as ISIC Rev. 4 B.C. The integration of these sources facilitates the construction of a database at the level of industrial establishment, encompassing information on both productive performance and innovation efforts, thereby enabling a detailed analysis of the relationship between innovation, R+D, productivity, and financial performance in the Colombian industrial sector.

The configuration of the dataset is consistent with an unbalanced panel, given that not all establishments are represented in all years of the analysis period. This phenomenon is attributable to the inherent dynamics of the manufacturing sector, including market entries and exits, business closures, and alterations in the criteria for inclusion in the sample. These elements mirror the evolution and heterogeneity of the industry during the period under investigation.

The focal point of this research endeavors to concentrate on micro and small enterprises in the Colombian industrial sector, given their pertinence in the generation of employment, productive development, and their capacity for technological absorption. Nevertheless, in order to identify structural gaps, an explicit comparison is made with medium and large companies. This comparison allows for the analysis of the heterogeneity in the relationship between innovation, R&D, and financial performance according to company size.

2.4. Defining Variables

The research is carried out based on the following variables:

1. Dependent variables
- ROA (return on assets): definition, formula, interpretation.
2. Key Explanatory Variables
- Innovation: Total number of innovations of new services or goods
- Investment in R+D: Internal and external R+D activities, amount invested
3. Control variables
- valorven: net sales (in thousands of COP).
- Pertotal: Total personnel employed.
- ActivFi: Fixed assets.
- Valorcom: National purchases.
- ValorCX: External purchases.
- PorCVT: Exports.
4. Other variables
- ISIC 4: Sectoral classification.
- Department: territorial location.
- Period: temporary variable for fixed effects.

Table 1 presents the annual distribution of the number of manufacturing firms included in the database, disaggregated according to firm size into micro, small, medium, and large enterprises. Both the absolute count of establishments and their percentage share of the total number of firms surveyed in each year of the analysis period are reported.

Table 1. Number of firms by size, and participation per year

Year	**Microenterprise**		**Small**		**Median**		**Big**	
2013	1,972	23%	4,218	48%	1,852	21%	667	8%
2014	1,880	22%	4,070	48%	1,850	22%	668	8%
2015	1,203	16%	3,853	50%	1,869	24%	732	10%
2016	1,359	18%	3,804	49%	1,854	24%	714	9%
2017	1,365	18%	3,618	49%	1,753	24%	688	9%
2018	1,292	18%	3,459	48%	1,759	24%	702	10%
2019	1,139	17%	3,178	47%	1,697	25%	727	11%
2020	1,476	22%	2,860	44%	1,542	23%	684	10%

From 2013 to 2020, small businesses have consistently constituted the predominant proportion of the business sector, with a percentage ranging from 48% to 50% in the majority of years. Conversely, microenterprises exhibit a more erratic participation rate, ranging from 16% to 23%, with a significant decline observed in 2015 and 2019, years in which their share decreased to 16% and 17%, respectively. This phenomenon may be associated with the inclusion criteria applied by DANE or with fluctuations in the economic activity of smaller firms.

In regard to medium-sized companies, their percentage of the total number of firms surveyed has remained relatively stable, ranging from 21% to 25%. Conversely, large companies constitute the least numerous group, with a percentage ranging from 8% to 11%. However, their economic and productive weight is disproportionately greater compared to their number. This aspect will be analyzed in the following subsections.

It is noteworthy that the year 2020 signifies a marginal reconfiguration of the business structure: microenterprises augmented their participation to 22%, potentially as a consequence of formalization strategies or a response to the circumstances precipitated by the COVD-19 pandemic, while small companies diminished their participation to 44%, representing the lowest value in the period under scrutiny.

Figure 1 illustrates the progression of investments in research and development (R+D) activities by micro and small manufacturing companies from 2013 to 2020. A discernible disparity in investment levels is evident, with small companies constituting the primary contributors to R+D expenditure throughout the observed period.

Microenterprises, on the other hand, have demonstrated a tendency to maintain relatively stable levels of investment, with a maximum of 909 million pesos recorded in 2017. In contrast, small companies have exhibited a more dynamic behavior, with a notable peak in 2018, when they invested more than 34 billion pesos. This discrepancy is indicative of the structural constraints that microenterprises encounter when attempting to engage in technological innovation processes.

Figure 1. Amount invested in R+D, micro and small firms

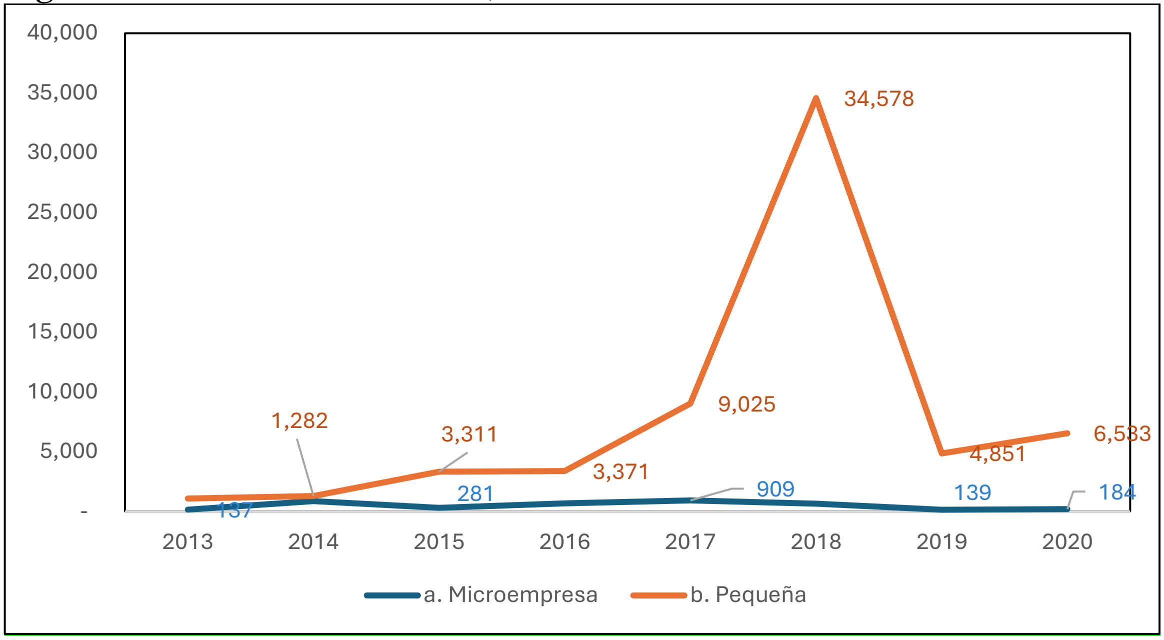


Figure 2 illustrates the evolution of the amount invested in research and development (R+D) activities by medium and large companies between 2013 and 2020. During the observed period, prominent corporations exhibited markedly elevated levels of investment, reaching a zenith in 2015 that neared one trillion pesos (988,729 million), followed by a gradual decline until it stabilized at approximately 447,838 million in 2020. Conversely, medium-sized companies recorded significantly lower investment amounts, with the year 2015 registering an investment of 114,374 million pesos. However, this figure underwent an abrupt decrease in the subsequent years, remaining below 30,000 million for the majority of the period under analysis. This discrepancy indicates a heightened degree of investment in innovation among larger firms, signifying their augmented financial and technological capabilities to support knowledge-intensive processes.

Figure 2. Amount invested in R+D, medium and large firms

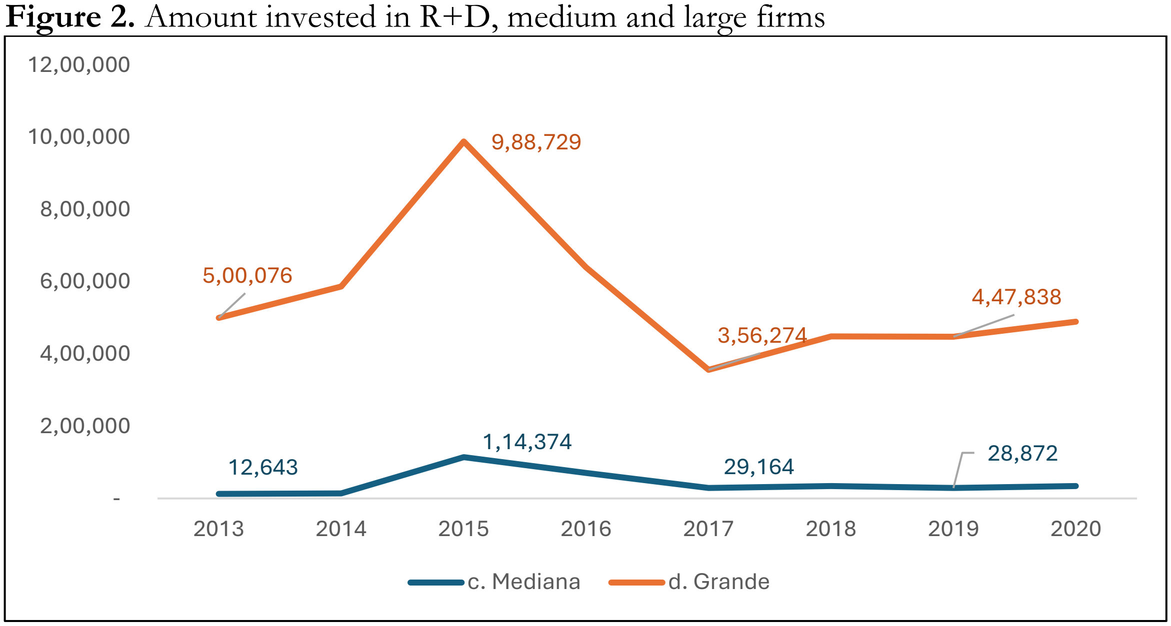
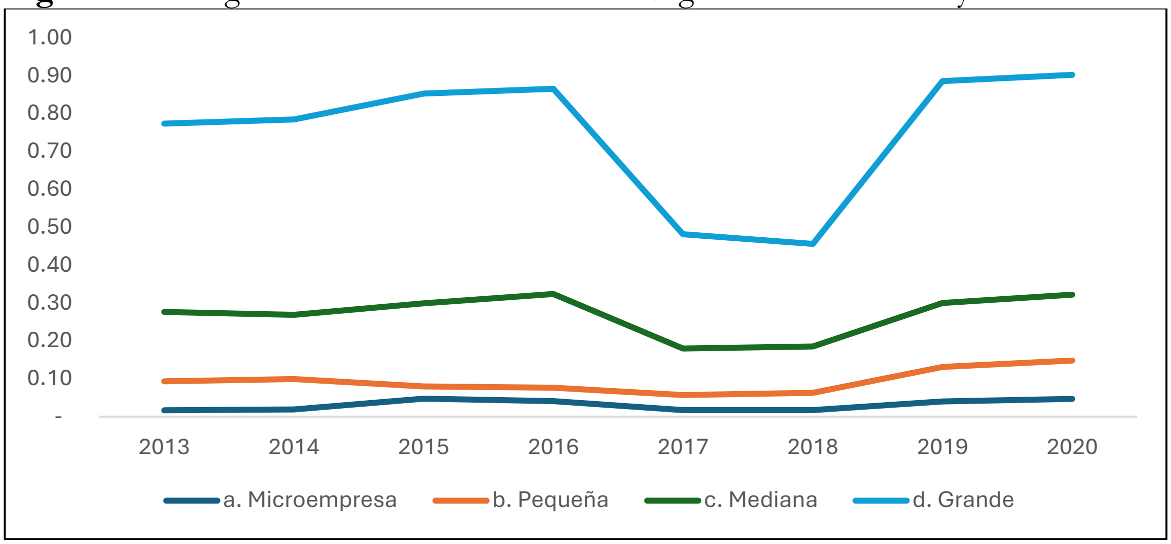


Figure 3 presents the mean number of innovations in new goods and services reported per firm, by size, over the period 2013–2020. Large companies consistently dominate this indicator, with most exhibiting an average of nearly one innovation per firm annually. Notwithstanding a precipitous decline between 2017 and 2018, the data demonstrate a resumption of an upward trend from 2019 onward, reaching levels approaching 0.9 in 2020.

In contrast, medium-sized companies exhibit a more stable pattern, with average values ranging from 0.25 to 0.35 innovations per firm. Conversely, small and micro enterprises exhibit the lowest levels, with averages below 0.15 and 0.05, respectively. This distribution reveals a discernible discrepancy in the generation of innovations based on firm size, thereby substantiating the hypothesis that business scale is closely associated with innovative capacity.

Figure 3. Average number of innovations in new goods and services by firm size



As illustrated in Table 2, the mean values for sales, fixed assets, labor force, consumption of raw materials, and electricity consumption are presented for different company sizes. All monetary figures are expressed in thousands of Colombian pesos. As anticipated, prominent corporations demonstrate remarkably elevated levels across all metrics, with mean sales reaching approximately 273 billion pesos, fixed assets amounting to 183 billion, and an average workforce of 474 employees.

As the magnitude of the firm is diminished, these means decrease proportionately. The financial statements of microenterprises indicate an average sales figure of 412 million pesos, with an average asset value of 603 million and an average employment level of 11 employees. This indicates that microenterprises possess limited capital structures and productive scales. The consumption of factors such as raw materials and electricity also evidences this hierarchy, with a high concentration of resources in the segments of medium and large companies. The information presented herein establishes a comparative basis, thus enabling the interpretation of the differences in productivity and financial performance in the subsequent sections of the analysis.

Table 2. Sales and Average Factor Consumption by Company Size

Size	Sales	Fixed assets	# Workers	Raw material	Electricity (kw)

Micro	412,589	603,805	11	253,536	29,341
Small	2,441,474	1,982,548	33	1,036,135	138,331
Median	18,498,791	12,318,308	130	8,700,568	1,114,721
Big	272,654,294	183,063,784	474	164,661,663	19,039,275

In conclusion, as illustrated in Table 3, the mean return on assets (ROA), exports, and imports are presented according to company size. While the return on assets (ROA) value is positive in all segments, a marked difference is evident between small/medium-sized companies and their larger counterparts: while small and medium-sized companies exhibit an ROA of more than 70%, large and micro companies attain an ROA of less than 60%.

With regard to foreign trade, substantial disparities are also evident. Large companies, in contrast, have average exports that exceed 45 billion pesos and imports that surpass 33 billion pesos. This is a stark divergence from the levels observed among microenterprises, whose average exports are less than 12 million pesos and imports are less than 3 million pesos. The findings indicate a discrepancy in financial performance, concomitant with a notable concentration of international participation among larger companies.

Table 3. ROA, Average Exports and Imports by Company Size

Size	ROA	Exports	Imports
Microenterprise	49.02%	12,069	2,628
Small	77.46%	120,076	49,887
Median	71.10%	2,179,574	1,536,007
Big	57.76%	45,095,512	33,951,682

3. METHODOLOGY

This section delineates the methodology employed in the analysis of the research object in the data. First, the variables to be used are described, differentiating between dependent and independent variables. Consequently, the group of explanatory variables is subdivided into the variables of interest (innovation and investment indices in R+D) and controls. It is imperative to underscore that total factor productivity is not directly observable; consequently, it must be inferred through the utilization of advanced micro-econometric methodologies. The subsequent process to estimate this variable is meticulously delineated. Finally, the model employed to analyze the relationship between the performance of firms, innovation, and investment in R+D is detailed.

The research employs a quantitative approach, utilizing a correlational-causal design. The microdata from the Annual Manufacturing Survey (EAM) and the Survey of Development and Technological Innovation (EDIT), prepared by the National Administrative Department of Statistics (DANE), are utilized. In this section, the scope, coverage, and characteristics of the sample from both surveys are examined. For further information, please refer to the methodological sheet, which can be accessed via the following link: The EAM sheet is a document that contains essential information regarding the maintenance and management of equipment. It is a crucial tool for any organization that aims to optimize the efficiency and reliability of its equipment. The period of analysis encompasses the years 2013–2020, thereby ensuring the comparability of the databases utilized in this research study.

3.1. Financial Performance Indices

To capture the ability of companies to create value, using their assets, the ROA ratio is used.

$$ROA = \frac{UTI_{it}}{ATC_{it}}$$

Where UTI_{it} is the net profit of the company i during the period t and ATC_{it} represents assets.

3.2. Total factor productivity

In order to estimate productivity, it is necessary to develop a model that accurately reflects the decision-making process of firms regarding the demand for inputs to be utilized in production and subsequently offered in the final market. This process entails the characterization of the production technology employed by firms, that is, the relationship between the inputs utilized and the quantity produced, as well as the interaction with the demand in the market for the final good. The present study employs the methodology proposed by Olley & Pakes (1996), Levinsohn & Petrin (2003), and Loecker (2011). These scholars have developed microeconometric approaches that allow for addressing problems of endogeneity and selection bias in the estimation of production functions. Consequently, this methodological approach guarantees a more accurate estimation of total factor productivity.

Each firm is expected to convert inputs into outputs in accordance with a Cobb-Douglas-type production function. This is:

$$1)\ Q_{it} = {L_{it}}^{\alpha_l} {M_{it}}^{\alpha_m} {K_{it}}^{\alpha_k} \exp\left(\omega_{it} + u_{it}\right)$$

Where Q_{it} is the firm's actual income, L_{it} is the labor factor (total number of workers), M_{it} raw materials (firms' consumption of raw materials and electricity), K_{it} capital (book value of the firms' equipment and land), ω_{it} the firm's productivity and u_{it} an innovation that is not observable for the firm. Income is deflated using the four-digit PPI. Capital and materials are also deflated, using a four-digit capital goods index and a four-digit intermediate consumption price index for industries, respectively. On the other hand, the coefficients α_l, α_m, α_k represent product-input elasticity and are parameters to be estimated.

On the other hand, it is assumed that the M_{it} and L_{it} factors are variable (they have no adjustment costs, which are called static inputs) while the K_{it} factor is fixed (dynamic) and adjusts according to the following law of motion:

$$K_{jt} = (1-\delta)K_{jt-1} + I_{jt-1}$$

Where I_{jt-1} is the investment in fixed capital.

Productivity is assumed to follow a first-order, potentially non-linear, exogenous Markov process known to firms, but not observable to the econometricist:

2) $\omega_{it} = E[\omega_{it}|\omega_{it-1}] + v_{it} = g[\omega_{it-1}] + v_{it}$

This establishes how firms form their expectations about the future trajectory of productivity. At time t, we observe ω_{it}, and it is predicted ω_{it+1} based on $g[\omega_{it}]$. Therefore, productivity is additively separable into an expected component $g[\omega_{it-1}]$ and a crash v_{it}, belonging to the set of information in t, although it is unpredictable for the firm in $t-1$.

3.2.1. Signature Maximization Process

The maximization process is divided into two parts: short-term maximization and long-term maximization. In period t, the firm observes its productivity innovation (v_{it}), its capital (k_{it}), the price of its variable factors (w_{it}) and (p_{mit}) (that the firm takes as given[1]) and aggregate industry demand; and based on this set of information, it optimally chooses the number of static factors to use (short-term maximization). Additionally, it uses $g[\omega_{it}]$ to predict the future trajectory of their productivity in order to then optimally choose the amount of investment in knowledge and the amount of investment in physical capital, that is, the capital of the moment (long-term maximization).

Given this *timing* The firm's choice of inputs suggests that both the l_{it} factor as m_{it} are contemporaneously correlated with productivity innovation and productivity itself (both in t), while the k_{it} factor is orthogonal to productivity shocks at t. In the long term, the following value function is obtained[2]:

3) $V(s_{it}) = \max_{i_{it}^*, d_{it}} [\pi_{it}(s_{it}) - C_{i^*}(i_{it}) + \frac{1}{1+\rho} E[V(s_{it+1})|s_{it}, i_{it}^*]]$

Where $s_{it} = (k_{it}, \omega_{it}, w_{it}, p_{mit})$ is the state variable vector of the firm. $C_{i^*}(i_{it})$ it is the adjustment cost function of physical capital.

From this dynamic programming problem derives the policy function for investment in physical capital. However, as Olley and Pakes (1996) point out, the policy functions associated with dynamic inputs are often intractable and, in many cases, do not even present an explicit analytical form, which prevents their direct use in econometric exercises. To overcome this limitation, the empirical strategy focuses on the use of static inputs, which are selected by firms to maximize their profits in the short term. These static input demands allow the unobserved productivity to be identified semi-parametrically and controlled in the estimation of the parameters of the production function, as well as in the estimation of the productivity motion law. In this context, in the short term, the firm solves the problem of maximization:

$$\pi_{it} = E_t(P_{it}Q_{it}) - w_{it}L_{it} - P_{mit}M_{it} - C_{i^*}(i_{it})$$

The expected value is necessary since both in the demand and in the production function there are variables that are not observable for the firm at the time it makes its decisions. This maximization leads to the demands of static factors, which depend on the state variables:

$$M_{it}^* = M_t(K_{it}, \boldsymbol{\omega_{it}}^*, q_{jt})$$
$$L_{it}^* = L_t(K_{it}, \boldsymbol{\omega_{it}}^*, q_{jt})$$

[1] Se supone competencia perfecta en el mercado de factores.

[2] $\pi_{it}(s_{it})$ es la función de ganancias maximizada en los factores estáticos.

Thanks to the assumption of perfect competition in the factor market, the prices of these do not vary between firms, they only vary over time, so to take into account that these affect demands, it is enough to place a subscript of time in the functions.

3.2.2 Estimating Productivity

Estimating exploits the static demand for materials and the *timing* of the choice of inputs. Assuming that the demand for materials is monotonous increasing in productivity, this can be reversed:

$$\boldsymbol{\omega_{it}}^{*} = M_t^{-1}(K_{it}, M_{it}^{*}) = h(K_{it}, M_{it}^{*})$$

Therefore, productivity can be obtained as a (non-linear) combination of capital and materials. Including this in the income function, the following is obtained:

$$\widetilde{q_{it}} = \beta_l l_{it} + \beta_m m_{it} + \beta_k k_{it} + \boldsymbol{\omega_{it}}^{*} + \xi_{it}^{*} + u_{it}^{*}$$

$$\widetilde{q_{it}} = \beta_l l_{it} + \beta_m m_{it} + \beta_k k_{it} + h(k_{it}, m_{it}^{*}) + \xi_{it}^{*} + u_{it}^{*}$$

Grouping yields:

4) $\widetilde{q_{it}} = \beta_l l_{it} + \Phi(K_{it}, M_{it}^{*}) + \xi_{it}^{*} + u_{it}^{*}$

Where $\Phi(k_{it}, k_{it}^{*}) = \beta_m m_{it} + \beta_k k_{it} + h(k_{it}, k_{it}^{*})$. When approaching $\Phi(.)$ using Taylor series, equation 7 can be estimated using OLS. This allows us to identify only the labor factor parameter. The capital and material factor parameters cannot be identified, since they affect the product directly (their elasticities) and through $h(.)$. To identify them, we use the fact that capital at t and material lags are orthogonal to productivity innovation at t (v_{it}). This is because, i) The firm only observes v_{it} from period t onwards, so that the capital (k_{it}), which is chosen in $t-1$, is independent of this innovation. ii) the above applies to m_{it-1}, because these are chosen before observing v_{it}, so they are orthogonal to this innovation.

Given the above, to obtain the estimated parameters of $m_{it} and\ k_{it}$, GMM chooses the set of parameters that minimizes the distance function created from the following moments:

$$E\left\{v_{it}(\beta_m, \beta_k)\begin{pmatrix} m_{it-1} \\ k_{it} \end{pmatrix}\right\} = 0$$

What is sample terms translates into:

5) $\frac{1}{N}\frac{1}{T}\sum_i \sum_t \left\{v_{it}(\beta_m, \beta_k)\begin{pmatrix} m_{it-1} \\ k_{it} \end{pmatrix}\right\} = 0$

The procedure is as follows:

i. From the estimation of equation 7, the predicted value of the function $.\Phi(.)$ is obtained

ii. An initial value of the parameters to be estimated (β_m^0, β_k^0) is chosen.

iii. Productivity is calculated based on these parameters. This is achieved by subtracting $\widehat{\Phi_t}(.)$ the quantities $\beta_m^0 m_{it}$ and $\beta_k^0 k_{it}$, which gives an estimate of $h(k_{it}, m_{it}^{*})$, that is, productivity expressed as the inverse function of material demand.

iv. With ω_{it} estimated, that is, $h(.)$ estimated, the regression is run $\omega_{it} = g[\omega_{it-1}] + v_{it}$ and an estimate of v_{it}. The function $g(.)$ is unknown, so it is approximated using a third-order polynomial in ω_{it-1}.

v. With $\hat{v}_{it}$ the norm of the vector from equation 8 (the momentum conditions vector) is obtained.

vi. β_m^0 and β_k^0 are modified to minimize the norm of the moment vector.

Since the procedure involves several stages, it is used to obtain the standard errors. The estimated productivity is obtained as:

$$\widehat{\omega}_{it}^{*} = \widetilde{r_{it}} - b_l l_{it} - b_m m_{it} - b_k k_{it}$$

3.3. Innovation and R+D measurement indices

To measure innovation and R+D spending, the following approach is used:

- Innovation
  - Total number of innovations of new services or goods in a given year.
- R&D
  - Amount invested in internal R+D activities, plus investment in the acquisition of external R+D.

3.4. Relationship between innovation and R+D and firm performance

The main hypothesis to be tested in this document is that greater innovation and greater spending on R+D implies greater performance of the company. For this, the following econometric specification is used:

$$Perform_{it} = \alpha_0 + \beta_1 I_{it} + \beta_2 ID_{it} + \boldsymbol{x}'_{it}\boldsymbol{\gamma} + \varepsilon_{it} \quad [1]$$

Where $Perform_{it}$ represents the firm's financial or technical performance index, approximated by financial profitability (ROA) and total factor productivity. On the other hand, I_{it} represents the innovation index for a company i at the moment t, ID_{it} represents spending on I+D, and $\boldsymbol{x}'_{it}$ is a vector of controls, ε_{it} a random disturbance term and $\boldsymbol{\alpha}_0$, β_1, β_2 and $\boldsymbol{\gamma}$ are the parameters to be estimated. The statistical significance and magnitude of the parameters β_1 and β_2 will reveal the impact of I_{it} and ID_{it} on the firm's performance.

In addition to controls, the various aggregate shocks that can affect firms in a more or less homogeneous way should be taken into account, such as the level of economic activity of the country (GDP), inflation, the exchange rate, etc. To do this, fixed time effects (v_t), are included in the model, which would be controlling for any factor that varies over time and is constant between signatures:

$$Perform_{it} = \alpha_0 + \beta_1 I_{it} + \beta_2 ID_{it} + \boldsymbol{x}'_{it}\boldsymbol{\gamma} + v_t + u_{it} \quad [2]$$

In this same sense, it is likely that there are factors that are not observable at the firm level that are relevant in the equation to be estimated. To control for these, another model is specified that includes, in addition to fixed time effects, fixed signature effects (ϵ_i):

$$Perform_{it} = \alpha_0 + \beta_1 I_{it} + \beta_2 ID_{it} + \boldsymbol{x}'_{it}\boldsymbol{\gamma} + \epsilon_i + v_t + u_{it} \quad [3]$$

In the event that $\hat{\beta}_1$ *and* $\hat{\beta}_2$ are positive and significant, there would be evidence in favor of the hypothesis that firms that innovate and invest more in R+D in the long run have a better position in the market compared to firms that invest less. This fact could be used by the government to create incentive schemes that lead the Colombian manufacturing industry to improve its performance, both technically and financially.

4. RESULTS

4.1. Production function

As illustrated in Table 4, the estimates of the production function are presented using three distinct methodologies. The ordinary least squares (OLS) method, the maximum likelihood (MCO) approach with fixed effects per signature, and the semiparametric method, which utilizes intermediate consumption as the control variable to correct for concurrency bias, are the three methodologies under consideration. Each of these approaches enables the analysis of the relationship between the factors of production (labor, capital, materials, and electricity) and the value added by micro-manufacturing enterprises. This methodological comparison provides a comprehensive perspective on the sensitivity of the estimated coefficients to the control of unobserved heterogeneity and simultaneity, thereby strengthening the empirical validity of the results obtained (Levinsohn & Petrin, Estimating Production Functions Using Inputs to Control for Unobservables, 2003).

Table 4. Estimating the Production Function

	(1)	(2)	(3)
VARIABLES	MCO	MCO and EF	LP
Electricity	0.163***	0.184***	0.0506***
	(0.00235)	(0.00291)	(0.00354)
Work	0.708***	0.597***	0.399***
	(0.00414)	(0.00598)	(0.0100)
Capital	0.0863***	0.0309***	0.0839***
	(0.00179)	(0.00165)	(0.00448)
Materials	0.176***	0.137***	0.0986***
	(0.00128)	(0.00149)	(0.00732)
Constant	6.998***	8.481***	
	(0.0208)	(0.0324)	
-			
Observations	60,504	60,504	60,504
R-squared	0.843	0.960	
Fixed effects		Signature	
Standard errors in parentheses			
p<0.01, ** p<0.05, * p<0.1			

In the initial model, estimated by Ordinary Least Squares (OLS) without additional controls, it is observed that all the productive variables are highly significant and have coefficients of relevant magnitudes. Labor exhibits the highest coefficient (0.708), indicating that a 1% increase in the number of workers is associated, on average, with a 0.708% increase in output. The subsequent categories, in descending order, are materials (0.176), electricity (0.163), and capital (0.0863). It is noteworthy that all of these categories were statistically significant at the 1% level. The coefficient of determination (R^2) of 0.843 indicates that this model accounts for a significant portion of the variability in output.

However, the primary limitation of this approach is that it does not control for unobservable heterogeneity between firms or correct for simultaneity bias between input use decisions and productivity, which has the potential to overestimate the magnitude of the estimated coefficients.

To address this limitation, the second model incorporates fixed effects per firm, which allows controlling for time-variant characteristics that could bias the estimates. Such characteristics may include managerial efficiency, organizational culture, or the intrinsic technological quality of each company. When these effects are included, a reduction in the coefficients of all inputs is observed, reflecting that part of the associations identified in the initial model were influenced by constant unobservable factors. For instance, the labor coefficient declines to 0.597, suggesting that the positive correlation between employment and production persists, albeit to a lesser extent when accounting for unobservable heterogeneity. Notwithstanding this reduction, all coefficients maintain a positive sign and statistical significance. It is noteworthy that R^2 increases to 0.960, indicating a substantial enhancement in the model's explanatory capacity by effectively controlling for unobserved variations between firms.

However, both previous models remain vulnerable to endogeneity problems arising from the simultaneity between input use decisions and productivity shocks. In order to address this issue, the approach delineated in the third column is employed. This method utilizes intermediate consumption (e.g., materials) as a proxy for unobserved productivity. Consequently, it facilitates a more consistent estimation of the coefficients associated with the production function. Under this approach, input coefficients are reduced in magnitude, though they maintain their statistical significance. The work currently presents a coefficient of 0.399, materials of 0.0986, capital of 0.0839, and electricity of 0.0506, indicating that all factors continue to have a positive and significant impact on production, albeit of a smaller magnitude compared to previous models.(Levinsohn & Petrin, Estimating production functions using inputs to control for unobservables, 2003)

The observed reductions indicate that prior estimates may have been biased upwards due to the exclusion of unobservable productivity-related variables. This underscores the necessity of utilizing simultaneity-correcting methods to ensure the accuracy of subsequent estimates.

4.2. R+D, innovation and productivity – Micro enterprises

As illustrated in Table 5, the regressions conducted aimed to ascertain the impact of investment in R&D, innovation, the number of workers (as a control for firm size), exports, and imports on productivity and the return on assets (ROA) of micro-manufacturing enterprises. The incorporation of fixed effects per signature is intended to regulate constant unobservable heterogeneity over time. The inclusion of exports is justified insofar as exporting firms tend to exhibit higher levels of productivity, either by self-selection of the most efficient firms towards international markets or by the learning effects derived from interaction with these markets. In a similar vein, the importation of inputs is regarded as a pertinent factor, given that importing firms often possess access to superior quality inputs or technology, thereby enhancing their average productivity. This set of explanatory variables facilitates a comprehensive analysis of the relationship between innovation efforts and investment in R+D with the operational and financial performance of microenterprises. The analysis incorporates dimensions of trade openness and size structure as determinants of productivity and profitability.

In the context of productivity analysis, it has been observed that investment in R&D exerts a positive and statistically significant effect on models (2) and (3). This effect is evident in models (2) and (3) with coefficients of 0.0901 and 0.102, respectively. These results suggest that an increase in R+D effort is associated with modest increases in total factor productivity. This finding is consistent with the extant literature that indicates that R+D drives technological improvements and efficiency gains in firms. However, this effect is not observed in model (4), which incorporates fixed effects per firm. This could indicate that part of the impact of investment in R+D is captured by constant unobservable characteristics at the firm level, such as its innovative trajectory, organizational capacities, or previously established management practices. This finding underscores the necessity of incorporating unobservable heterogeneity between firms into analyses of the impact of R+D on productivity. This is due to the potential for structural or historical advantages to partially explain the observed relationship in models without fixed effects.

Conversely, the innovation index has been shown to have no statistically significant impact on productivity in any of the three specifications. This outcome may be attributable to the constraints imposed by the utilized metrics, which might not adequately capture the full scope of technological advancements. Alternatively, it could be attributed to the temporal diffusion of innovation's impact on productivity, which is contingent on its interaction with other factors, such as human capital and the technological absorption capacity of firms.

In all three productivity models, the number of workers exhibits a negative and highly significant coefficient. This finding can be interpreted as evidence of diminishing returns to scale in the microenterprise segment. Alternatively, it could be interpreted as an indication that a larger size in terms of employment does not necessarily translate into greater efficiency. This could be due to management or internal coordination problems. Conversely, the export sector has been shown to exert a positive and significant influence on all models, thereby substantiating the hypothesis concerning the acquisition of knowledge in international markets and the self-selection of the most productive firms toward export activity. Finally, an examination of the models reveals that imports exert a positive effect on models (2) and (3). However, this effect is no longer evident in model (4) when fixed effects are incorporated, thereby suggesting that the observed outcomes are influenced by non-observable factors that are unique to each firm. These factors may include the supplier structure, the quality of inputs utilized, or the production strategies employed by the firm.

Table 5. R+D, innovation and productivity – Micro enterprises

	(2)	(3)	(4)	(6)	(7)	(8)
VARIABLES	Productivity	Productivity	Productivity	ROA	ROA	ROA
R&D	0.0901	0.102*	0.0507	-12.05	4.917	27.25
	(0.0602)	(0.0613)	(0.0636)	(12.36)	(9.999)	(28.59)
Innovation	-0.00594	0.00372	0.0492	-1.918	-13.03	-18.91
	(0.0547)	(0.0534)	(0.0602)	(4.107)	(16.74)	(21.47)
# Workers	-0.116***	-0.122***	0.120***	-77.59	-74.87	19.42

	(0.0244)	(0.0247)	(0.0333)	(77.75)	(74.80)	(19.41)
Exports	7.29e-08**	6.02e-08**	2.30e-08	0.000143	0.000155	2.45e-05
	(3.13e-08)	(2.80e-08)	(1.57e-08)	(0.000170)	(0.000181)	(3.05e-05)
Imports	2.40e-07	2.39e-07	-4.72e-08	-6.24e-05	-3.71e-05	7.61e-06
	(2.10e-07)	(2.19e-07)	(2.26e-07)	(6.25e-05)	(4.41e-05)	(2.92e-05)
Constant	9.567***	9.581***	9.021***	202.7	196.1	-21.50
	(0.0565)	(0.0574)	(0.0779)	(201.2)	(194.0)	(45.69)
Observations	11,686	11,684	10,713	11,571	11,569	10,603
R-squared	0.009	0.049	0.633	0.001	0.005	0.310
Fixed effects		Period, Department, ISIC	Period, Department, ISIC, Signature		Period, Department, ISIC	Period, Department, ISIC, Signature
Robust standard errors in parentheses						
p<0.01, ** p<0.05, * p<0.1						

In regard to the relationship between investment in R+D, innovation, and financial performance, as measured by return on assets (ROA), the results indicate a considerably weaker relationship. The findings indicate that the coefficients associated with the R+D or innovation variables are not statistically significant in models (6), (7), and (8). This suggests that, at least in the short term, investments in innovative activities do not result in increased profitability on assets in micro-manufacturing enterprises. This finding aligns with the extant literature that indicates the financial effects of innovation tend to require longer periods to materialize, especially in smaller firms that face capital constraints, greater vulnerability to external shocks, and longer innovation cycles.

In these models, the number of workers exhibits a negative coefficient, albeit without statistical significance. The variables of exports and imports, however, do not demonstrate consistent or significant effects. These results serve to reinforce the hypothesis that the financial performance of microenterprises is more influenced by financial and commercial factors, as well as the macroeconomic environment, than by the mere adoption of innovation or internationalization strategies. It is also posited that for investments in innovation and R+D to be translated into sustainable improvements in the ROA, complementary conditions are likely to be required. Such conditions may include organizational capacities, access to adequate financing, and the stability of public policies that allow these impacts to be consolidated over time.

4.3. R+D, innovation and productivity – Small companies

As illustrated in Table 6, the findings of the regressions for small firms are presented. In the context of productivity, column (2) of the data reveals a statistically significant positive relationship between investment in R+D and productivity, with a coefficient of 0.0421 and a p-value of 0.05. This indicates that for every 1% increase in investment in R+D, productivity increases by 0.0421%, which is a statistically significant increase. This finding indicates that an augmentation in investment in R+D activities is associated with a modest increase in the technical efficiency of small firms, which is consistent with the extant literature on innovation-driven growth. The aforementioned literature posits that R+D contributes to the improvement of processes and the adoption of technologies that increase total factor productivity.

However, in columns (3) and (4), where fixed effects per firm are incorporated, the R+D coefficient loses statistical significance and its magnitude is considerably reduced. This phenomenon suggests that the beneficial impacts of investment in R+D may be absorbed by inherent characteristics at the company level, including organizational culture, innovative trajectory, and technological capabilities that have been accumulated over time. In this sense, the importance of considering the specific heterogeneities of each firm to properly understand the relationship between investment in R+D and productivity is highlighted, as well as the need to complement innovation strategies with organizational capacities that allow materializing and sustaining these effects in the long term.

Conversely, the innovation variable has been shown to exert a positive influence on productivity in model (2), exhibiting statistical significance at the 10% level and a coefficient of 0.0335. This finding suggests that innovative endeavors may be exerting a direct influence on the technical efficiency of small companies, underscoring the notion that the adoption of novel practices or products contributes to enhanced resource utilization. However, this effect dissipates in models that incorporate fixed effects per firm, thereby indicating that the advantages of innovation on productivity may be influenced by invariant characteristics at the firm level, such as organizational structure, accumulated experience in innovation, or technological absorptive capacity.

With respect to the analysis of control by company size, the number of workers exhibits a negative coefficient in all specifications, with significance in models (3) and (4). This pattern suggests that an increase in the workforce does not necessarily lead to higher levels of productivity, unless it is accompanied by improvements in organizational management and technological processes that facilitate the efficient use of the workforce.

With regard to the variables of trade liberalization, the findings indicate a positive and significant impact on exports across the three models. This observation lends support to the hypothesis that engagement in international markets is associated with enhanced efficiency levels. This enhanced efficiency may be attributed to either the self-selection of more productive companies towards export, or the accumulation of knowledge from operating in these markets. Furthermore, the findings reveal that imports exhibit positive and significant impacts in models (2) and (3), yet these impacts become less pronounced in model (4). This observation suggests that a portion of the impact of imports on productivity may be associated with specific characteristics of firms that remain constant over time.

With respect to return on assets (ROA), models (6) to (8) fail to demonstrate substantial evidence that investment in R+D or innovation engenders statistically significant effects on the financial profitability of small companies. While the innovation coefficients are positive in models (6) and (7), with magnitudes approaching 156, they do not attain statistical significance. In the more restrictive model (8), which incorporates fixed effects per signature, the sign of the coefficient is inverted, indicating high sensitivity to the specification. Conversely, investment in R+D has been observed to exhibit negative

coefficients in all specifications, though these results did not attain statistical significance. This suggests that the financial benefits derived from innovation and R+D activities in small firms may require a longer time horizon to materialize or are subject to high variance due to sectoral heterogeneity and organizational capabilities.
Conversely, the number of workers does not exert a significant influence on ROA, suggesting that workforce size is not a primary determinant of profitability within this group of companies. Furthermore, the variables of trade openness, as measured by exports and imports, demonstrate an absence of consistent or significant impacts across all the specified analyses. The findings of this study lend further credence to the hypothesis that the financial profitability of small firms may be contingent, to a greater extent than has been previously documented, on contextual factors, financial management, market conditions, and marketing strategies, rather than on isolated innovative efforts in the short term.

Table 6. R+D, innovation and productivity – Small companies

	(2)	(3)	(4)	(6)	(7)	(8)
VARIABLES	Productivity	Productivity	Productivity	ROA	ROA	ROA
R&D	0.0421**	0.0216	0.00683	-69.72	-70.91	-52.65
	(0.0177)	(0.0175)	(0.0127)	(68.50)	(70.30)	(52.73)
Innovation	0.0335**	0.0177	0.0126	156.4	158.2	192.6
	(0.0170)	(0.0163)	(0.0118)	(157.8)	(159.0)	(192.9)
# Workers	0.00782	0.0226**	0.00370	5.166	0.323	47.49
	(0.00906)	(0.00908)	(0.0139)	(5.002)	(2.447)	(47.41)
Exports	9.42e-09	8.60e-09	4.14e-09	-7.16e-07	-7.59e-08	-1.83e-07
	(9.88e-09)	(9.46e-09)	(3.93e-09)	(8.87e-07)	(3.52e-07)	(2.60e-07)
Imports	1.55e-07***	1.56e-07***	8.57e-08***	-7.48e-06	-1.76e-06	-8.81e-06
	(2.88e-08)	(2.88e-08)	(1.41e-08)	(6.58e-06)	(2.11e-06)	(8.87e-06)
Constant	10.26***	10.21***	10.28***	-11.86	3.640	-153.4
	(0.0305)	(0.0303)	(0.0455)	(14.69)	(8.389)	(162.6)
Observations	29,060	29,059	28,310	28,996	28,995	28,246
R-squared	0.013	0.093	0.731	0.001	0.004	0.145
Fixed effects		Period, Department, ISIC	Period, Department, ISIC, Signature		Period, Department, ISIC	Period, Department, ISIC, Signature
Robust standard errors in parentheses						
p<0.01, ** p<0.05, * p<0.1						

4.4. R+D, innovation and productivity – Medium-sized companies

As illustrated in Table 7, the regressions for medium-sized enterprises consistently demonstrate a positive and significant effect of investment in R+D on total factor productivity. In model (2), which does not include fixed effects per firm, the R+D coefficient is 0.0702 and is significant at the 1% level, indicating a substantial impact of investment in knowledge on technical efficiency. When introducing controls by period, department, and ISIC in the model (3), the coefficient decreases to 0.0440, yet remains highly significant. This suggests that part of the relationship is explained by contextual factors, without eliminating the positive effect of R+D. In the most stringent model (4), which incorporates fixed effects per firm to control for invariant characteristics such as organizational capabilities, innovative culture, or historical technological structures, the effect of investment in R&D remains significant at 5%, with a coefficient of 0.0205.

These findings serve to reinforce the hypothesis that, in medium-sized manufacturing firms, the capacity for technological innovation, when supported by systematic investment in R+D activities, translates into sustained productive improvements, regardless of their structural characteristics that are invariable over time. The robustness of this effect in disparate empirical specifications indicates that public policy and business management strategies designed to promote investment in research and development may serve as an effective mechanism to enhance the technical efficiency and competitiveness of this business segment in Colombia.

Table 7. R+D, innovation and productivity – Medium-sized companies

	(2)	(3)	(4)	(6)	(7)	(8)
VARIABLES	Productivity	Productivity	Productivity	ROA	ROA	ROA
R&D	0.0702***	0.0440***	0.0205**	-2.014	-0.658	-0.182
	(0.0170)	(0.0163)	(0.00877)	(1.352)	(0.517)	(0.168)
Innovation	0.00245	-0.0105	0.00395	-1.325	-1.001	0.0566
	(0.0160)	(0.0146)	(0.00935)	(0.911)	(0.626)	(0.0784)
# Workers	-0.169***	-0.0976***	-0.0887***	4.332	4.902	-3.067
	(0.0155)	(0.0163)	(0.0215)	(3.125)	(3.564)	(2.376)
Exports	7.11e-09***	9.46e-09**	1.24e-08***	-5.40e-08	-1.29e-07	3.82e-08
	(2.70e-09)	(4.03e-09)	(3.41e-09)	(4.75e-08)	(9.91e-08)	(2.91e-08)
Imports	2.43e-08***	2.15e-08***	1.05e-08***	-2.07e-07*	-1.48e-07*	9.70e-09
	(2.43e-09)	(2.67e-09)	(1.50e-09)	(1.20e-07)	(8.89e-08)	(2.17e-08)
Constant	12.00***	11.68***	11.65***	-16.67	-19.43	16.14
	(0.0708)	(0.0727)	(0.0974)	(12.97)	(15.09)	(10.90)
Observations	14,176	14,173	13,702	14,155	14,152	13,680
R-squared	0.126	0.287	0.839	0.003	0.009	0.737

Fixed effects		Period, Department, ISIC	Period, Department, ISIC, Signature		Period, Department, ISIC	Period, Department, ISIC, Signature
Robust standard errors in parentheses						
p<0.01, ** p<0.05, * p<0.1						

Conversely, innovation, conceptualized as an independent variable of R+D, exhibited no substantial impact on the three productivity models for medium-sized companies. Despite the persistent positive nature of the coefficients, they fail to attain statistical significance, which may suggest that the utilized indicators are not sufficiently adept at capturing the innovations that effectively influence technical efficiency. Conversely, this outcome indicates that, within this business sector, the implemented innovations may be more incremental in nature or predominantly oriented towards commercial and market considerations, exhibiting a lesser direct impact on total factor productivity (TFP).

Conversely, the number of workers exhibits a negative and statistically significant relationship with productivity in the three specifications, which may reflect the presence of diminishing returns to scale in medium-sized manufacturing companies or evidence limitations in organizational structures to efficiently manage the increase in workforce. This finding suggests that, within this business group, the expansion of the workforce without concomitant technological improvements, organizational innovation, or management capacity building may prove counterproductive to productivity.

The findings of this study demonstrate that exports exert a positive and significant influence on productivity across various metrics. The magnitude of this influence ranges from 7.11e-09 to 1.24e-08, indicating a substantial impact on productivity levels. This finding aligns with the observed pattern in other business segments, suggesting that firms operating in international markets tend to exhibit higher levels of efficiency. This efficiency may be attributed to self-selection, where the most productive firms are those that successfully export their products and services. Alternatively, this efficiency could be the result of the benefits gained from operating in more demanding and competitive markets, which provide opportunities for learning and growth. In a similar vein, the findings indicate that imports exhibit positive and significant coefficients, thereby substantiating the hypothesis that enhanced access to superior inputs or foreign technological resources contributes to the augmentation of productive efficiency among medium-sized manufacturing enterprises.

With respect to return on assets (ROA), models (6), (7), and (8) demonstrate that investment in R+D and innovation do not have a statistically significant impact on financial profitability. Despite the negative innovation coefficients in specifications (6) and (7) and the slight positive coefficient in (8), they are statistically indistinguishable from zero in all cases. Conversely, the R+D ratios are found to be negative and non-significant, thereby indicating that investments in innovation and development activities do not result in increased returns on assets for medium-sized firms, at least in the short term. This result aligns with the extant literature on the subject, which indicates that the financial benefits derived from R+D tend to manifest themselves with lags, particularly in manufacturing sectors where the cycles of development, adoption, and technological diffusion are usually extensive.

4.5. R+D, innovation and productivity – Large companies

In conclusion, as illustrated in Table 8, the regressions pertinent to large manufacturing firms are presented. The findings indicate a discernible and substantial correlation between investment in research and development (R+D) and total factor productivity (TFP) across the initial two specifications. In model (2), the R+D coefficient is 0.0888 and is significant at the 1% level. In model (3), which incorporates fixed effects by period, department, and ISIC, the coefficient remains highly significant (0.0745). These findings suggest that investment in R+D exerts a positive and significant effect on the technical efficiency of large firms, consistent with the extant literature emphasizing the capacity of these firms to transform R+D endeavors into enduring productive advancements. Nevertheless, incorporating fixed effects for each firm in the model (4) results in the R+D coefficient becoming non-significant and its magnitude being considerably diminished. This finding indicates that the inherent characteristics of each firm, including its organizational structure, innovation trajectory, and the quality of its human capital, account for a substantial proportion of the initially ascribed positive effect of investment in R+D.

With regard to the innovation variable, a positive and significant relationship with productivity is demonstrated in the initial two specifications. In model (2), the coefficient is 0.0896 and is highly significant, indicating that large companies that adopt innovations tend to achieve relevant improvements in their technical efficiency. In model (3), the coefficient decreased to 0.0414, yet it remained statistically significant at the 10% level. However, when controlling for fixed effects per firm in the model (4), this effect disappears, suggesting that the impact of innovation on productivity is mediated by specific and persistent attributes of each firm, such as its organizational culture, consolidated technological capabilities, and internal knowledge management processes, which also have a direct impact on productive performance.

In consideration of the firm's size, as quantified by the number of employees, the findings are indicative of either diminishing returns to scale or scalability challenges inherent in large enterprises. The associated coefficient is negative and significant in all three specifications, with values ranging from -0.208 to -0.266. This suggests that an increase in the number of employees does not necessarily result in a proportional increase in production. This finding indicates that large firms may experience organizational inefficiencies when they expand their workforce without implementing technological or managerial improvements that ensure efficient use of resources.

Conversely, exports and imports persist in their role as pivotal drivers of productivity for substantial firms. The findings indicate that exports have a positive and significant impact on productivity, with coefficients reaching the order of 10^{-9}. This observation suggests that companies operating in international markets tend to exhibit higher levels of productivity. This phenomenon can be attributed to either a process of self-selection by which the most efficient firms survive and thrive, or to the learning acquired through global competition. In a similar vein, imports, functioning as a proxy for access to higher-quality inputs or advanced technologies, also demonstrate positive and statistically significant effects on productivity, albeit with smaller magnitudes than those observed in the case of exports.

With regard to the return on assets (ROA), the results demonstrate a distinct dynamic in comparison to that observed in previous business groups. For large companies, a positive relationship is identified between investment in R+D and ROA in the model (8), with a coefficient of 0.0807, significant at 10%. This finding suggests that, in contrast to micro, small, and medium-sized enterprises, large firms are beginning to translate their R+D investments into financial improvements, although the effect is still of moderate magnitude. In models (6) and (7), the R+D coefficient is also positive, but it is not statistically significant. This finding indicates that the financial impact of innovation on large firms may be subject to high variability and require more detailed analyses or longer panels to be identified with greater robustness.

Table 8. R+D, innovation and productivity – Large companies

	(2)	(3)	(4)	(6)	(7)	(8)
VARIABLES	Productivity	Productivity	Productivity	ROA	ROA	ROA
R&D	0.0888***	0.0745***	-0.00399	0.0620	0.0532	0.0807*
	(0.0274)	(0.0219)	(0.0107)	(0.0431)	(0.0413)	(0.0445)
Innovation	0.0896***	0.0414*	0.00611	0.00913	-0.0339	-0.0287
	(0.0315)	(0.0230)	(0.0120)	(0.0356)	(0.0304)	(0.0246)
# Workers	-0.208***	-0.0945**	-0.266***	-0.190***	-0.194***	-0.383***
	(0.0280)	(0.0434)	(0.0661)	(0.0510)	(0.0503)	(0.104)
Exports	1.95E-09***	1.36e-09***	8.65e-10***	1.62e-09**	1.46e-10	2.22e-10
	(1.76e-10)	(1.85e-10)	(2.09e-10)	(7.52e-10)	(3.60e-10)	(6.64e-10)
Imports	1.35e-09***	1.05e-09***	2.74e-10***	-1.44e-09***	-0	0
	(1.82e-10)	(1.96e-10)	(9.29e-11)	(4.86e-10)	(2.38e-10)	(2.40e-10)
Constant	13.52***	12.92***	14.01***	1.822***	1.878***	2.953***
	(0.161)	(0.244)	(0.378)	(0.294)	(0.289)	(0.598)
Observations	5,582	5,580	5,392	5,581	5,579	5,391
R-squared	0.331	0.646	0.924	0.045	0.350	0.554
Fixed effects		Period, Department, ISIC	Period, Department, ISIC, Signature		Period, Department, ISIC	Period, Department, ISIC, Signature
Robust standard errors in parentheses						
p<0.01, ** p<0.05, * p<0.1						

With regard to the impact of innovation on return on assets (ROA), the findings indicate a lack of statistical significance across all specifications, with contradictory signs observed among the models. This phenomenon may be attributed to the tendency of large corporations to adopt innovations that do not primarily seek to yield immediate financial returns. Instead, these innovations are often directed towards enhancing strategic capabilities, streamlining internal processes, or fortifying market positioning, all with a view to long-term strategic objectives. Conversely, the number of workers exerts a negative and significant influence on ROA in models (6) and (7), indicating that increases in the workforce may be associated with a reduced return on assets. This phenomenon may be attributed to higher cost structures or the gradual absorption of financial benefits derived from organizational changes. The findings indicate that exports exert a positive and significant influence on ROA across all three specifications, suggesting that the internationalization of large companies is associated with higher financial returns. In contrast, the analysis of imports reveals that their impact on profitability is only significant in model (6). However, when specific characteristics of each firm are taken into account, the significance of imports is diminished. This suggests that the impact of imports on profitability may be contingent on the persistent internal factors of the firm.

5. DISCUSSION

The findings indicate that investment in R&D and innovation exerts heterogeneous effects on the productivity and profitability of companies according to their size, particularly within the context of the Colombian manufacturing sector. Firstly, the study corroborates the hypothesis that investment in R+D significantly improves productivity. This finding is consistent with previous research that documented the positive relationship between innovation and productivity in Colombia. For instance, it was determined that the introduction of novel goods and services resulted in a significant increase in both sales per worker and total factor productivity, underscoring the pivotal role of innovation as a catalyst for efficiency enhancement within manufacturing enterprises.(Arbeláez & Parra, 2011)

For micro and small enterprises, initial investment in R&D has been shown to have positive impacts. However, these effects are attenuated when fixed effects per firm are incorporated, suggesting that internal structural factors exist that limit their ability to capitalize fully on the benefits of innovation. This dynamic corresponds with the documented evidence regarding the obstacles encountered by SMEs in Colombia. Such obstacles include, but are not limited to, limited technological adoption and knowledge barriers (Departamento Nacional de Planeación [DNP], 2016; Busom & Ospina, 2017). Furthermore, studies have shown that only firms with greater absorption capacities are able to effectively leverage the benefits of innovation in terms of productivity and performance (Departamento Nacional de Planeación [DNP], 2016; Busom & Ospina, 2017).

Secondly, within the context of large industrial firms, both product innovation and R&D have been observed to exert a more pronounced and sustainable influence on productivity, even when controlling for unobservable heterogeneity. The present result aligns with the findings reported by , who determined that R+D activities and technological adoption facilitate the introduction of new products, thereby contributing to an elevated MIP (measure of innovation) and enhancing productivity. With regard to financial profitability (ROA), the effects are more modest. A positive relationship between R+D and ROA was identified in large companies, in line with the idea that the financial returns of innovation tend to materialize with lags and require consolidated organizational capacities. (Salas, Arias, & Valencia, 2023; Arbeláez & Parra, 2011; Busom & Ospina, 2017)

The findings of this study underscore the necessity for a nuanced industrial policy. Micro and small enterprises stand to benefit from targeted support to surmount organizational impediments and attain optimal returns on their investments in innovation. Conversely, within large corporations, the enhancement of the congruence between resources allocated to R&D and innovation strategies has the potential to engender substantial advancements in both productivity and profitability.

6. CONCLUSIONS

Empirical evidence demonstrates that investment in R&D exerts a positive and significant effect on productivity in companies within the Colombian manufacturing industry, particularly among large and medium-sized enterprises. Conversely, in micro and small companies, the impact of investment in R&D is mitigated when controlling for unobservable heterogeneity, suggesting the presence of structural barriers that impede the efficacy of innovation in these segments. The present study finds support for the extant literature on the subject, thereby confirming the positive relationship between innovation efforts and total factor productivity. However, the findings indicate that this relationship is subject to variation in terms of intensity and sustainability, a variation that is contingent upon the size of the firm in question.

The findings of this study demonstrate that investment in research and development (R+D) and innovation activities exert a heterogeneous impact on the productivity and financial profitability of manufacturing companies in Colombia, contingent on their size. In particular, it has been confirmed that R+D contributes significantly to the increase in productivity, especially in medium and large companies, where these effects are maintained even when controlling for unobservable heterogeneity. Conversely, within the context of micro and small enterprises, the impact of R&D and innovation is often mitigated when firm-specific structural factors are taken into account. This suggests limitations in the capacity of these enterprises to fully capitalize on the benefits of innovation.

In regard to financial performance (ROA), a negligible relationship between R+D or innovation is observed in the majority of cases. However, a positive, albeit modest, effect is identified in the case of large companies. This finding suggests that the financial benefits derived from innovation tend to materialize with lag and require robust organizational capacities and stability in the innovation strategy to consolidate profitability.

In a similar vein, exports and imports have been shown to have a positive effect on productivity across all segments. This lends further support to the notion that internationalization is a valid learning strategy, facilitating technological absorption and enhancing the productive capacities of Colombian companies.

These results underscore the necessity for a diversified industrial policy approach, wherein micro and small enterprises necessitate comprehensive support, encompassing facilitated access to credit, fortified organizational capacities, and technical assistance to surmount obstacles to technological adoption. Conversely, medium and large companies stand to benefit from policies that prioritize the promotion of applied R+D, the deepening of university-business alliances, and the integration of advanced technologies. These measures are expected to enhance their capacity for innovation, thereby exerting a positive influence on productivity and profitability.

In contexts characterized by informality, financing constraints, and institutional instability, such as Colombia's, it is imperative that public policies are implemented in a comprehensive manner, ensuring continuity and inter-institutional coordination to maximize the effectiveness of innovation strategies. This will enable companies to optimize the returns on their investments in innovation, thereby generating sustainable impacts on productivity, competitiveness, and industrial development in the country.

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