

Determinants of pioneering technological innovations in the Brazilian manufacturing industry

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Abstract

The capacity to innovate drives competitiveness and economic development. From this perspective, the aim of the present study is to improve understanding of the relationship between innovation and its determinants in Brazil's manufacturing industry during the period 2015–2017. Using data from the 2017 Technological Innovation Survey, the authors estimated a generalized linear model with a negative binomial distribution. The findings show that technological capability and expenditure on innovation activities were decisive and positively associated with the number of innovating firms. By contrast, financing or sources of support for innovation, firm size and economic risks were not statistically significant. Lastly, government financial support showed no meaningful impact on innovation, raising doubts about the efficiency of such support, which was received by fewer innovating firms (26.2%) in 2015–2017 compared with previous three-year periods, potentially contributing to the weakness of innovation activities.

Keywords

Industrial enterprises, industrial development, technological innovations, measurement, industrial statistics, statistical methodology, industrial policy, Brazil

JEL classification

O14; O25; O33

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I. Introduction

Owing to globalization and increasingly competitive markets, it is essential that public and private organizations invest in innovative products and processes. The capacity to develop innovations drives economic development, and the countries that have made the greatest progress in innovation are also those that have invested and continue to invest in research and development.

Accordingly, high-income economies occupy leading positions in the Global Innovation Index published by the European Institute of Business Administration. Switzerland, for example, has led the ranking since 2000. Brazil, by contrast, ranked fifty-seventh among the 132 economies analysed in 2021 and placed fourth within Latin America and the Caribbean, behind Chile (fifty-third), Mexico (fifty-fifth) and Costa Rica (fifty-sixth).¹ This scenario illustrates that the Brazilian economy faces numerous challenges that must be addressed. In a highly unequal country such as Brazil, persistent problems related to poverty, health and the quality of education, for example, pose obstacles to the development of science, technology and innovation.

In the face of inequality and the problems it generates, compounded by the magnitude of the crisis triggered by the coronavirus disease (COVID-19) pandemic, risk aversion may increase considerably and, consequently, countries and firms may face greater difficulties in attracting investment and promoting innovation. In this context, innovating is not easy and requires substantial effort on the part of both public and private institutions. It is precisely because of these difficulties, however, that the country should strengthen scientific and technological development. By enabling a more efficient use of resources, innovation can help to reduce the problems facing Brazil. This context provides the rationale for the present study, which is intended to support public and private agents in designing policies for fostering innovation-related activities by identifying the factors that most strongly influence such activities in Brazilian industry.

The manufacturing sector was selected for analysis owing to its broad scope and importance for the Brazilian economy. It currently accounts for 11.2% of GDP, 65.1% of corporate investment in research and development, 46.2% of Brazilian exports of goods and services and 24.1% of federal tax revenues (National Confederation of Industry, 2024). However, as in other countries, the sector's share of GDP has been declining. In addition, Brazilian industry has fallen 10 places in the ranking of the Competitive Industrial Performance Index of the United Nations Industrial Development Organization, moving from thirty-second to forty-second place in the period 2010–2019 (United Nations Industrial Development Organization [UNIDO], 2025). This index measures countries' capacity to produce and export manufactured goods, the degree of technological intensification and upgrading and their impact on global markets. Brazil's performance indicates that the country remains far from the technological frontier.

Despite Brazil's weaker-than-expected performance in innovation and competitive industrial indices, a study by the Organisation for Economic Co-operation and Development (OECD, 2020) points to the country's considerable, as yet untapped, potential in emerging digital technologies, such as the Internet of things and big data. The manufacturing sector could achieve productivity and efficiency gains, reduce costs and enhance sustainability, provided that certain problems—such as the complexity of the tax system and limited access to credit for small firms with high innovative potential—are resolved.

Despite differences in research objectives, studies have focused on uncovering data that explain the relationship between innovation and its determinants in Brazil's industrial sector. Innovation is more likely to occur among firms that undertake greater efforts to innovate, including investments in

¹ See Dutta et al. (2022) for further details on the Global Innovation Index of 2021.

research and development, maintain a workforce with a larger share of employees holding university degrees and receive greater government support. International empirical research in recent years has linked firm characteristics to innovation, indicating that research and development investment, export experience, government subsidies and reduced barriers to innovation contribute to firms' likelihood of innovating. These studies are presented in section II.

Although there is an extensive body of literature on the subject, the innovation indicator used in this study refers specifically to innovations that did not previously exist in the domestic market. This indicator may be considered novel insofar as it captures only genuinely pioneering innovations and excludes product or process innovations that are new to the firm but already exist in the domestic market. Moreover, no studies were identified in specialized journals that use data from the 2017 Technological Innovation Survey (PINTEC).

Against this backdrop, the general objective of this study is to analyse the relationship between innovation and its determinants in Brazil's manufacturing industry during the period 2015–2017. Specifically, the analysis focuses on the effects of the employees, technological capability, government support, expenditure and economic risk variables on innovation activities oriented towards the domestic market.

It is expected that technological capability, investment in research and development, firm size and government support will be positively associated with the number of firms in each sector that introduced product or process innovations. Conversely, economic risk is expected to be negatively associated with innovation.

The article is divided into four sections in addition to this introduction. Section II presents the theoretical and empirical foundations of the relationship between innovation and its determinants. Section III outlines the methodology. Section IV includes the presentation and discussion of results and section V sets out the main conclusions of the study.

II. Theoretical and empirical aspects of innovation and its determinants

1. Theoretical aspects

In his book *The Theory of Economic Development*, Schumpeter was the first to conceptualize innovation as the principal driver of capitalist dynamics —that is, the main mechanism through which capitalism develops. Within this framework, he introduces the concept of the “entrepreneur” as the agent responsible for bringing innovation into industry. The Schumpeterian entrepreneur is responsible for transforming and revolutionizing the prevailing model through the exploitation of an invention or a new technology (Schumpeter, 1934).

According to Schumpeter (1942), both industrial and technological revolutions facilitate the continuous emergence of new products, processes and organizational forms. In this way, innovation generates ongoing industrial change that transforms the economic structure and thus becomes essential to economic development. For the author, innovation is pursued continuously to obtain strategic advantages, based on two central concepts: monopoly profits and creative destruction.

For Schumpeter, monopoly profits are the outcome of the competitive process and represent the gains derived from innovation until competitors replicate it. Creative destruction, meanwhile,

refers to the process whereby firms initially introduce new products—or produce existing products through different processes—and subsequent imitation by competitors gives rise to new ideas and processes, thereby fostering further innovation by the entrepreneur.

Another important Schumpeterian idea is that large firms contribute a relatively significant share to technological progress (Schumpeter, 1934). The rationale is that larger firms are better able to spread the fixed costs of innovation, benefit from economies of scale in research and development, access greater internal resources and leverage complementarities between research and development and other processes. However, subsequent studies questioning this hypothesis found that no systematic relationship can be established between firm size and the intensity of research and development investment, since the determining factor is the type of industry under analysis (Cohen and Levin, 1989).

In their analysis of firm dynamics, Nelson and Winter (1996) also adopt the view that routines are complemented by the notions of selection and search.² Routines underpin the behaviour of agents and organizations, which innovate in order to survive through established rules and patterns of conduct—one of the central premises of the neo-Schumpeterian approach (Nelson and Winter, 1996). According to the authors, the trajectory of technical progress becomes endogenous, emerging from the solutions developed to address everyday problems. In the same evolutionary vein, Possas (2008) argues that technical progress is introduced through two fundamental mechanisms: the search for innovations, undertaken by firms through strategic action, and the selection of economic outcomes through the market and other institutions, such as research centres and universities.

Another key concept within the evolutionary perspective relates to search behaviour, which is inherently associated with risk (Rissardi et al., 2009). If search routines—manifested in research and development activities—are subject to some degree of uncertainty, the innovation process becomes guided by heuristics based on prior experience, including both successes and failures (Corazza and Fracalanza, 2004).

By emphasizing the role of behavioural routines, Nelson and Winter (1996) further advance theoretical understanding through the concept of “natural trajectories,” which strongly influence technological evolution. In doing so, they depart from neoclassical methodological assumptions of equilibrium, replacing them with the broader notion of trajectory, and substitute maximizing rationality with bounded or procedural rationality.

Rosenberg (1983) conceptualizes technological innovation as a learning process. In the economic literature, learning is understood as a cumulative process that enables firms to refine knowledge and strengthen their capabilities to develop, produce and commercialize goods and services (Rissardi et al., 2009).

According to Rosenberg (1969, 1983), this view challenges certain neoclassical assumptions, since uncertainty lies at the core of innovative activity and is essential to understanding the nature of innovation. The outcomes of technological change involve complex relationships that cannot be fully anticipated *ex ante*, and both the rate of adoption and the direction of innovation depend on expectations regarding future technological learning. Furthermore, the level of accumulated learning directly influences the trajectory of technological change.

In this context, firms' innovative capabilities are shaped by research and development activities, as well as by learning by doing, learning by using and learning by interacting (Rosenberg, 1983). The innovation process can thus be analysed in two stages: generation and diffusion. The accumulation

² Selection refers to the competitive process which, over time, favours the most effective routines (both strategic and operational), thereby generating differentiation among firms in terms of their market performance. When competitive conditions no longer align with the strategies adopted by firms or with their implementation, firms initiate a search for new routines, understood as processes inherently associated with risk (Rissardi et al., 2009).

of these capabilities, together with technological assets, determines both the type and intensity of innovation and contributes to the development of firms' trajectories, as learning may hold the key to enhancing productivity in high-technology industries.

According to Freeman (1974) and Freeman et al. (1982), it is essential to examine the technological strategies within which firms operate in the innovation process. The authors characterize this process as interactive: in addition to acquiring knowledge through their own experience, development and production, firms continuously learn from their relationships with various external sources. Accordingly, the role of scientific knowledge highlighted by Freeman is not exogenous to the innovation process; instead, it is increasingly embedded in the interaction between science and technology.

Freeman et al. (1982) identify six types of technological strategy, which vary across firms: offensive, defensive, imitative, dependent, traditional and opportunistic. The offensive strategy characterizes firms seeking technological leadership in the market; they maintain strong internal research and development processes that play an important role in seeking knowledge from basic research. Similarly, firms adopting a defensive strategy do not aim to launch entirely new products but focus on refining existing innovations. These firms are typically risk-averse but still invest intensively in research and development.

Firms pursuing an imitative strategy do not aim for technological leadership in the market and engage in limited research and development, focusing mainly on adapting to local conditions and optimizing production processes. In the dependent strategy, unlike the others, firms do not conduct research and development, as they are economically and institutionally reliant on other firms. Their resources are thus devoted primarily to production and commercialization.

Lastly, neither traditional nor opportunistic strategies involve research and development activities. In the traditional strategy, firms' products remain unchanged because competition does not stimulate innovation, resembling a perfectly competitive or oligopolistic market structure. By contrast, firms adopting opportunistic strategies focus on occupying market niches that rely on specific product knowledge for particular customers.

The innovation process can be understood as the interaction between firms and the alternatives offered by a technological paradigm. Dosi (1982) refers to the concept of "technological paradigms" to explain the determinants, procedures and directions of technological change, as well as its effects on industrial performance and the structural transformation of organizations.

According to Dosi et al. (1990, p. 84), a technological paradigm can be defined as a "pattern' of solution of selected problems based on highly selected principles derived from prior knowledge and experience". In this way, technological paradigms define the opportunities for subsequent innovations while establishing the basic procedures that enable their exploitation. Building on this framework, Dosi (1984) introduces the concept of "technological trajectories" in a detailed analysis of the mechanism linking technological change to the socioeconomic system.

This concept is particularly useful for the empirical analysis of organizations, as it indicates the direction taken by technical progress. According to Cardoso (2003, p. 64), a technological trajectory reflects the action of technological progress within a given technological paradigm; in other words, it represents the "normal" way of developing and seeking solutions to specific problems.

Differences in technological capabilities among firms arise from their specific characteristics and depend on changes in their technological trajectories. Accordingly, paradigm shifts, together with development along these trajectories, create the opportunities that firms can exploit in pursuit of profits (Tigre, 2005).

2. Empirical analysis of the relationship between innovation and its determinants

By incorporating the evolutionary perspective on innovation into analyses, many empirical studies have focused on identifying the organizational, institutional and economic characteristics considered determinants of technological innovation (De Marchi, 2012). Factors such as information and knowledge flows, technological and internal absorptive capabilities, sectoral characteristics, firms' innovative behaviour and financing conditions have increasingly been included in these studies (Veugelers, 2012).

The emphasis on this topic and the use of diverse methodologies and indicators in recent decades have made this research even more relevant.

Accordingly, the present study not only builds on the theoretical literature discussed above but also highlights national and international empirical evidence on the determinants of technological innovation in manufacturing activities.

Regarding the national literature, Quadros et al. (2000) identify four variables that condition technological innovation in industry: sector, technical production system, firm size and capital origin. On the basis of data from the São Paulo Economic Activity Survey, the authors conclude that larger firms in São Paulo exhibit significantly higher technological performance than small and medium-sized enterprises.

Using data from PINTEC 2000, Kannebley et al. (2004) find that the factors most strongly influencing a firm's likelihood to innovate were export orientation and firm size (measured by the number of employees). According to the authors, larger firms increase the probability of innovation in manufacturing more than proportionally. Notably, these key factors identified by Kannebley et al. (2004) are also observed in the studies of Póvoa and Monsueto (2011), Mohamed (2018) and De Freitas (2019).

With regard to expenditure on innovation activities (innovation effort), Carrara and Ferreira (2020) provide empirical support for the hypothesis that the number of firms investing in such activities positively influences the performance of the Brazilian manufacturing industry. These findings are replicated both in individual estimations and when the analysis is extended to all regions of Brazil over time.

Thus, investment in research and development, infrastructure and technology represents a viable alternative for developing countries seeking to accelerate their growth trajectory. Scherrer Mendes et al. (2020) find that narrowing the technological gap requires transforming the production structure and raising productivity through the endogenization of technological progress. Drawing on a multilevel analysis based on PINTEC data for 2008, 2011 and 2014, the authors further show that greater expenditure on research and development, machinery and equipment, and workforce training increases the likelihood that firms will innovate.

In the context of today's heightened competitive pressures, innovation costs have become a central consideration in firms' decision-making, as they may act as a barrier to the innovation process (Silva and Dacorso, 2014). The 2014 PINTEC report indicated that, in the manufacturing industry, high costs were regarded as the main obstacle to innovation, ranking first in importance relative to the 2008 and 2011 editions. Consistent with these findings, Silva and Dacorso (2014), in their analysis of innovation costs in the Brazilian manufacturing industry, showed that most sectors assigned high or medium importance to the impact of costs on innovation activities. Kühl and da Cunha (2013) likewise identified these costs as one of the main economic obstacles and barriers to innovation.

Technological capability is of paramount importance. Cohen and Levin (1989) define technological capability as the ability to recognize the value of new knowledge, assimilate it and apply it for commercial purposes. Given its direct linkage with research and development activities that enable the generation of new products or processes, technological capability is indispensable for innovation (Patel and Pavitt, 1994).

In analysing the determinants of innovation and firms' absorptive capacity in Brazil using PINTEC data for 2000 and 2003, De Negri (2006) found that firm-level characteristics related to the labour force, such as educational attainment and diversity of training, strongly influence technological innovation. Mohamed (2018) reached similar conclusions in an analysis of firm-, sector- and region-level factors affecting innovation in the Brazilian manufacturing industry using 2014 PINTEC data, highlighting technological capability and government support as the primary determinants of technological innovation in the country's industrial sector.

With regard to government support, although it remains a subject of debate, the State and public policies play a fundamental role in fostering innovation. According to Pinsky and Kruglianskas (2017), government incentives for innovation can operate through two channels, or a combination of both: technology-push and demand-pull. In the first case, the government acts by reducing the private cost of project development, whereas in the second, government support increases firm profits when innovations succeed.³

Avellar et al. (2021) highlight that government support, together with expenditures on research and development, access to information and obstacles to innovation, are important determinants of cooperation in innovation. In their study, the authors examine the factors driving cooperation in innovation, considering collaboration with both national and foreign institutions, as well as the types of partner, including other firms, business groups and research institutions.

Innovation requires substantial financial resources, largely in the form of investment in research and development, and may be reinforced by public policies that complement firms' own efforts through significant investment in research. Mendes and Rocha (2019) analyse the impact of public investment in research on firms' technological innovation performance. Using a sample of 2,500 firms across 45 countries, the authors estimate the effect of public investment on the relationship between firm performance and private investment in research and development. Their results indicate that public investment enhances the private returns on investment in research and development.

Consistent with the national literature on the determinants of innovation, international studies also identify key factors that shape the innovation process. Adams et al. (2016) investigate the impact of technological absorptive capacity in 549 firms located in Austria, Brazil, China, Germany, India and Singapore. Among their main findings, the authors report that technological capability has a positive and statistically significant effect on firm performance in these countries.

Sofka (2008) examines how German firms adapt their technological absorptive capacity to capitalize on opportunities in new markets. Research on the internationalization of innovation activities suggests that investments in research and development, the strength of the domestic market and firms' export experience all contribute to building technological capabilities at the national level.

In his thesis, De Oliveira (2019) analyses firms with innovation potential in developing countries and finds that institutional, market and knowledge-related factors are associated with technological innovation. Using data from Ecuador's National Survey of Science, Technology and Innovation Activities for the period 2009–2014, the author determines that characteristics such as knowledge and

³ Technology-push refers to subsidies for research and development initiatives, measures to enhance knowledge transfer capacity, support for educational programmes, training and project financing. Examples of demand-pull include intellectual property rights, tax credits and discounts for consumers of new technologies, regulatory frameworks and taxes applied to competing technologies (Pinsky and Kruglianskas, 2017).

market barriers are the most relevant constraints faced by Ecuadorian firms engaged in innovation activities. By contrast, an analysis conducted for Uruguay, covering 2001–2015 with data from the Innovation Activities Survey, shows that market barriers have a significant negative relationship with innovative productivity. Lastly, the analysis for Peru for the period 2009–2014 indicates that institutional factors, such as government support, have a positive and significant association with innovation activities, while innovation obstacles exhibit a negative relationship, as expected.

Exploring the effects of government subsidies, research, development and innovation on Chinese manufacturing industries between 2007 and 2017, Ahia et al. (2022) find a positive and significant causal relationship between investment in research and development and innovation. The authors also observe that firms classified as “younger” and State-owned achieve better short-term innovation performance than private firms. Furthermore, government subsidies not only stimulate short-term research and development but also foster long-term innovation and play a crucial role in research, development and innovation activities in emerging markets.

An extremely important aspect highlighted in the work of Yildiz et al. (2021) is absorptive capacity. According to the authors, this capacity can be developed at both the individual and collective levels, leading to positive outcomes in innovation. Because it reflects the ability to acquire and manage new ideas in the workplace, absorptive capacity plays a central role in promoting innovative processes.

In line with the objectives of this study, this section contributes to the selection of explanatory variables used in the regression model analysing the determinants of technological innovation in the manufacturing industry. Overall, both the national and international literature on the theory of innovation and its determinants in the manufacturing sector —both in Brazil and globally— is extensive and well established.

III. Methodology

1. Description of database and variables

The database used in this analysis was compiled from the 2017 edition of the PINTEC survey conducted by the Brazilian Institute of Geography and Statistics.

Initiated in the 2000s, PINTEC aims to construct sectoral, national and regional indicators of innovation activities undertaken by firms in the industrial sector (extractive and manufacturing industries), the electricity and gas sector and selected service activities. In addition, the purpose of the survey is to deepen the analysis of firms’ efforts to innovate in products and processes by identifying aspects such as expenditure on innovation activities, sources of financing, the role of government incentives, obstacles encountered, technology use, sustainability and environmental innovation (Brazilian Institute of Geography and Statistics [IBGE], 2020).

Accordingly, the dataset used in this analysis includes a sample of 3,695 firms distributed across 54 sectors of the Brazilian manufacturing industry. These firms introduced innovations considered new to the domestic market.

Table 1 presents the variables used to estimate the relationship between innovation and its determinants for manufacturing firms in Brazil. The selection of these variables was based on the theoretical and empirical studies discussed earlier. Table 1 also lists the studies that employed the selected variables and the expected signs for each variable.

Table 1
Description of the explanatory variables of the model

Variable	Description of variable	Studies	Expected sign
Innovation	Dependent variable (number of firms that introduced product and process innovations considered new to the domestic market).	None identified	–
Employees (<i>po</i>)	Proxy variable for firm size, measured by the number of persons employed on 31 December 2017.	Mohamed (2018), De Freitas (2019) and Avellar et al. (2021)	> 0
Technological capability (<i>captec</i>)	Number of employees with university degrees engaged in innovation activities.	Sofka (2008), Adams et al. (2016), Mohamed (2018), De Oliveira (2019) and De Freitas (2019)	> 0
Government support (<i>ag</i>)	Number of firms, by sector, that received some form of government support, including tax incentives, grants and public financing.	De Negri (2018), Mohamed (2018), Mendes and Rocha (2019), De Oliveira (2019), De Freitas (2019) and Ahia et al. (2022)	> 0
Expenditure (<i>dís</i>)	Number of firms, at the sectoral level, that invested in internal and external research and development activities, acquisition of external knowledge, acquisition of software, machinery and equipment, and training.	Mohamed (2018), Silva and Dacorso (2014), Mendes and Rocha (2019), De Freitas (2019), Scherrer Mendes et al. (2020) and Ahia et al. (2022)	> 0
Economic risk (<i>re</i>)	Number of firms, by sector, that attributed medium or high importance to problems and obstacles to innovation.	De Oliveira (2019) and Silva and Dacorso (2014)	< 0

Source: Prepared by the authors, on the basis of Mohamed, A. A. (2018). *Determinantes empresariais, setoriais e regionais da inovação: um estudo para a indústria de transformação* [Master's degree dissertation]. Federal University of Viçosa. <http://www.locus.ufv.br/handle/123456789/22501>; De Freitas, H. D. (2019). *Determinantes do consumo de água no processo produtivo da indústria de alimentos e bebidas* [Master's degree dissertation]. Federal University of Viçosa. <https://locus.ufv.br/handle/123456789/27404>; Avellar, A. P. M., Damasceno, A. O. and Silva, F. Q. (2021). Determinantes da cooperação para inovação das empresas brasileiras. *Economia e Sociedade*, 30(3). <https://doi.org/10.1590/1982-3533.2021v30n3art07>; Sofka, W. (2008). Globalizing domestic absorptive capacities. *Management International Review*, 48. <https://doi.org/10.1007/s11575-008-0106-9>; Adams, D. R., Flatten, T. C., Brinkmann, H. and Brettel, M. (2016). Consequences and antecedents of absorptive capacity in a cross-cultural context. *International Journal of Innovation Management*, 20(1). <https://doi.org/10.1142/S1363919616500031>; De Oliveira, F. S. (2019). *Obstáculos à inovação: determinantes, efeitos e complementaridades em países em desenvolvimento* [Doctoral thesis]. University of Santiago de Compostela; De Negri, F. (2018). *Novos caminhos para a inovação no Brasil*. Institute of Applied Economic Research; Mendes, H. D. and Rocha, L. A. (2019). *A contribuição dos investimentos públicos em pesquisa no desempenho da inovação das empresas* [Master's degree dissertation]. Federal Rural University of the Semi-arid Region; Ahia, B. N. K., Song, N., Anafo, S. A. and Boakye, E. A. (2022). A story conveyed for emerging economies: the transitivity effects of subsidy, R&D, and innovation within manufacturing industries. *IEEE Transactions on Engineering Management*, 69(6). <https://doi.org/10.1109/TEM.2020.3036614>; Silva, G. and Dacorso, A. L. R. (2014). Riscos e incertezas na decisão de inovar das micro e pequenas empresas. *Revista de Administração Mackenzie*, 15(4). <https://doi.org/10.1590/1678-69712014/administracao.v15n4p229-255>; Scherrer Mendes, P., Britto, G. and Hermeto, A. M. (2020). Brazilian industry and knowledge absorption: internal and external company determinants. *CEPAL Review* (131) (LC/PUB.2020/9-P/Rev.1). Economic Commission for Latin America and the Caribbean.

Note: The analysis covered 3,695 firms that introduced innovations new to the domestic market but already existing in the world market.

2. Generalized linear models

Generalized linear models are in a class that broadens the range of statistical analysis beyond the normal distribution, and are therefore used when the response variable being examined is a count, categorical or asymmetric variable restricted to positive values (Fávero and Belfiore, 2017). In this study, the response variable is the number of firms that implemented product and process innovations considered new to the domestic market. Accordingly, count data regression models were employed. Both the Poisson distribution model and the negative binomial distribution model were considered in the analysis. These models are described in detail in Fávero and Belfiore (2017).

Equation (1) presents the estimation of the parameters of the negative binomial distribution, the method selected for its superior fit to the data used in this study.

$$u_i = e^{\alpha + \beta_1 captec_i + \beta_2 ag_i + \beta_3 dis_i + \beta_4 po_i + \beta_5 re_i} \quad (1)$$

where *captec* denotes the sector's technological capability; *ag* represents government support provided to the sector; *dis* refers to the number of firms or sectors that incurred innovation-related expenditure; *po* corresponds to the number of employees at 31 December and serves as a proxy for firm size; and *re* is a variable reflecting economic risks and obstacles to innovation.

The model was subsequently evaluated to assess the goodness of fit of the chosen distribution and to identify poorly fitted and influential observations. Graphical analyses were used to examine the adequacy of the Poisson and negative binomial distributions. Diagnostic measures included Cook's distance, normal probability plots, standardized residual plots and hat matrix (\widehat{H}) values, which together helped to detect potential problems related to model fit.

3. Exploratory analysis and descriptive statistics

Regarding the variable measuring the number of firms that implemented product and process innovations, the variance (54,770.76) is substantially higher than the mean (214.19), suggesting the presence of overdispersion. Boxplots were also constructed for the independent variables to identify potential outliers (Faraway, 2014). When outliers were detected, logarithmic transformations were applied to reduce asymmetry in the distributions.

The exploratory analysis showed that the pharmaceutical chemicals sector had the lowest number of firms implementing product and process innovations in the period 2015–2017. A possible explanation, according to Mitidieri et al. (2015), is that the strengthening of Brazil's pharmaceutical industry in recent decades did not generate comparable opportunities for the pharmaceutical chemicals industry, which produces the primary raw materials for medicines. The rise of Asian countries as major suppliers of these inputs has challenged the competitiveness of Brazil's industry, as well as that of other non-Asian countries.

Conversely, the food industry registered the highest value for the response variable. Reflecting the sector's innovation potential in Brazil, driven by growing domestic and international demand, food manufacturers have invested in production capacity and efficiency, securing a prominent position in both domestic and international markets (Raimundo et al., 2017). Food production also accounts for the largest number of employees among the sectors analysed. Despite the impact of the COVID-19 pandemic, which increased production costs by 3.8% in 2020, the food and beverage industry created 20,000 new jobs, representing a 1.2% increase over the previous year. It thus remained the largest employer in Brazil's manufacturing sector, with 1.68 million direct jobs (Brazilian Packaging Association, 2021).

Concerning the number of firms per sector that invested in internal and external research and development activities, the national average over the three-year period was 168.5 firms, a figure considered low relative to previous years. According to the PINTEC report for the period analysed, the intensity of expenditure on total innovation activities in industry fell for the third consecutive time, standing at 1.65% in 2017 (IBGE, 2020). The chemical manufacturing sector recorded the highest level of investment, while the tobacco products sector had the lowest number of firms investing in research and development.

The data on the sources of financing for innovation activities indicate that, on average, 227.35 firms received some form of government support. Once again, the greatest support went to firms producing food products, while the lowest support went to those in the tobacco sector. As noted by Zajonz et al. (2017), Brazil is one of the leading global producers of tobacco, accounting for 11% of worldwide production. In 2014, the government collected approximately 12.8 billion reais

in taxes from this sector. However, in addition to the formulation of measures to discourage tobacco consumption through higher taxes, policies exclusive to this sector that promote production diversification among small rural producers and large industry players pose obstacles.

Lastly, the data on technological capability among employees indicate a limited level of development. On average, 1,325.7 employees with higher education work in manufacturing firms, representing only 0.8% of the total number of employees in the sample. According to the 2017 PINTEC report, 65.5% of innovative firms cited a lack of qualified personnel, making it the third most important obstacle to innovation (IBGE, 2020). In terms of extremes, the motor vehicles, trailers and coachwork manufacturing sector employed the largest number of highly educated personnel, while the printing and reproduction of recorded media sector reported the lowest.

IV. Results and discussion

As noted, the response variable corresponds to the number of firms that implemented product and process innovations for the domestic market. As a count variable, it requires a distribution suited to this type of data. Within generalized linear models, the Poisson distribution with a logarithmic link function is typically the initial specification. When the generalized linear model of the Poisson distribution does not provide an adequate fit, alternative models are considered, with the negative binomial distribution being the most commonly used in cases of overdispersion (De Freitas, 2019).

In addition to identifying overdispersion of the data, the selection of the best-fitting model was based on several statistical criteria. Table 2 presents the results of the likelihood ratio test and the Akaike information criterion for each of the models tested with different distributions. The results indicate that the negative binomial distribution provides a better fit to the data, as it yielded a lower Akaike information criterion and higher likelihood, and was therefore the model analysed in this study.

Table 2
Model selection for the dataset

Fit	Akaike information criterion	Log-likelihood
Poisson distribution	2 060	-1 024
Negative binomial distribution	590	-288

Source: Prepared by the authors.

As explained above, the estimated regression models aimed to relate the number of firms innovating in the Brazilian manufacturing industry to variations in technological capability, sector size, government support, the number of firms per sector that incurred expenditure on innovation, and economic risk. The results are shown in table 3. Model 1 was estimated using a negative binomial distribution by maximum likelihood. Model 2, the final model, was estimated using a stepwise procedure to ensure greater robustness of the estimates. This was the model used in the present study to interpret the results, together with the corresponding marginal effects.

According to the values presented in table 3, at any conventional level of significance, model 1 indicates that technological capability and the number of firms incurring expenditure on innovation are statistically significant. The fitted model also yielded a dispersion parameter greater than 1, which also explains the lack of fit of the Poisson distribution.

Table 3
Innovation and its determinants
(Dependent variable: innovation)

Variable	Model 1	Model 2	Marginal effects
Technological capability	0.1986** (0.0683)	0.1665 (0.0605)	0.3439** (0.1319)
Expenditure on innovation	0.6710*** (0.1995)	0.6009*** (0.1279)	1.2409*** (0.3018)
Government support	0.1905 (0.1316)	0.1797 (0.1293)	0.3711 (0.2702)
Employees	-0.1098 (0.1065)
Economic risks and obstacles	-0.0127 (0.1476)
Constant	0.5753 (0.8254)	-0.5907 (0.4742)	...
Dispersion parameter	5.89 (1.01)	4.97 (0.98)	...

Source: Prepared by the authors.

Note: *** significant at 1%; ** significant at 5%. Standard errors are reported in parentheses. The analysis covered 3,695 firms that introduced innovations new to the domestic market but already existing in the world market.

To preserve the robustness of the estimates in the presence of highly correlated variables, the employees and economic risks and obstacles variables⁴ were removed from the model using a stepwise procedure. Although both variables are theoretically relevant and have a strong influence on innovation performance, they are highly correlated. As noted by Chiarini et al. (2020), the larger the firm (as measured by the number of employees), the fewer obstacles to innovation it faces. Furthermore, the likelihood ratio test indicated that model 2 fits the sample data as well as model 1, which includes all variables. On this basis, the specification supported by the statistical tests was adopted.

The adequacy of the final model was assessed primarily through the residuals of the fitted model, considering three graphical measures commonly used in residual analysis: Cook's distance, standardized residual plots and hat matrix (\hat{H}) values.

Five observations stand out from the rest. These points should be examined carefully, as they may mask the effect of other variables in the model (masking effect). However, the specific treatment applied through confirmatory analysis indicated that these observations did not alter the inference of the selected model, and the variables should therefore be retained.

Lastly, at the 5% significance level, the Shapiro-Wilk and Breusch-Pagan tests indicated, respectively, that the residuals of the final model follow a normal distribution and that there is no evidence of heteroskedasticity.

Once the tests had been conducted and the model's robustness confirmed, the results were interpreted.

Regarding technological capability, it was found that a 1% increase in the number of employees with higher education corresponds to an approximate increase of 0.35 units in the number of firms implementing product and process innovations for the domestic market. This underscores the role of higher education institutions in training qualified professionals and researchers who,

⁴ Studies by Mohamed (2018), De Freitas (2019) and Avellar et al. (2021) found a positive and statistically significant relationship between firm size and innovation. By contrast, De Oliveira (2019) and Silva and Dacorso (2014) found a negative and significant relationship between economic obstacles and innovation. It should be noted, however, that none of these studies used both indicators simultaneously.

once integrated into firms, provide the tacit capacity to absorb technology, acquire it and apply scientific knowledge innovatively, whether in solving complex problems or engaging in research and development to create new products or services. The literature corroborates the findings of this study. De Negri (2006), Mohamed (2018) and Araújo and Garcia (2019) highlight the contribution of technological capability and higher levels of university research to innovation.

There was a positive and significant relationship between innovation effort, measured by the number of firms per sector investing in innovation activities, and the number of firms introducing innovations. Moreover, an increase of 1 unit in this variable corresponds to a 1.24-unit rise in the number of firms implementing product and process innovations. This result was expected and is consistent with the literature. For example, Figueiredo and da Costa (2019) highlight that average expenditure on research and development is one of the most important factors influencing innovation. Similarly, Mohamed (2018) concludes that spending on innovation activities is positively correlated with the number of firms introducing innovations.

Contrary to expectations, the variable representing the number of firms receiving government support was not significant. This result suggests that, during the period analysed, financing and support mechanisms for innovation were not relevant in explaining the number of firms innovating in the manufacturing industry. It is important to note that, over the past two decades, Brazil has implemented a series of measures aimed at strengthening scientific, technological and innovation capacity. Among the policies adopted are the Innovation Act (Act No. 10973 of 2004) and the Good Act (Act No. 11 196 of 2005).⁵ Brazil has put in place several instruments used in developed countries to promote innovation, including (i) subsidized credit, (ii) tax incentives, (iii) grants and (iv) funding for research projects in universities and scientific and technological institutions (De Negri, 2018).

According to De Negri (2018), public investment in science and technology in 2015 totalled approximately 33 billion reais. However, the allocation of this budget across the various ministries was markedly different from that of investments in science and technology in countries such as the United States. According to the author, unlike in other countries, most Brazilian investments are not linked to a specific mission. Therefore, there is no guarantee that financial support for innovation activities will effectively increase such activities.

Similarly, Gordon and Cassiolato (2019), who analysed the role of the State in promoting innovation through the *Plan Inova Empresa*, launched in 2013, corroborate the findings of this study. The authors show that, although the government implemented a set of advanced instruments to incentivize and support innovation activity, the policy outcomes did not achieve the intended effect. They conclude that these measures did not succeed in changing firm behaviour.

Zucoloto and Nogueira (2017) specifically analyse the support provided by the National Bank for Economic and Social Development (BNDES) for innovation activities from 2002 onward. Among the results of their evaluation of financing instruments and mechanisms, the authors highlight the growing role of innovation in BNDES disbursements to the manufacturing sector. However, even though non-automatic credit operations for innovation projects totalled 14.3 billion reais (6.5% of the total), traditional support mechanisms —such as tax incentives and financing for research and development projects— remain insufficient to generate and disseminate new products and processes in Brazil. One factor identified by the authors is that the 362 credit operations carried out between 2002 and 2015 covered only 168 manufacturing firms in the country.

⁵ The Innovation Act encouraged the public and private sectors to share personnel, resources and facilities in order to promote collaboration between universities, research institutes and private companies. The Good Act, meanwhile, expanded the scope and facilitated the use of tax incentives to support private investment in research and development (De Negri, 2018).

According to the PINTEC report for the 2015–2017 triennium, fewer innovating firms received government support for innovation (26.2%, compared with 34.2% in 2009–2011 and 39.9% in 2012–2014). Within industry, the share of innovative firms using financing instruments to acquire machinery and equipment fell from 31.4% in 2012–2014 to 14.1% in 2017. Conversely, the share of firms benefiting from tax incentives for research and development under the Good Act (Act No. 11 196 of 2005) increased from 3.2% to 4.3% (IBGE, 2020).

This situation, compounded by the COVID-19 pandemic, is having even greater repercussions for the Brazilian pharmaceutical chemicals industry. According to Paranhos et al. (2021), the pandemic showed the segment's dependence on the production of active pharmaceutical ingredients in Asian countries, particularly China and India. It also generated additional pressures owing to logistical disruptions caused by border closures and the suspension of transport services, including air transport. Market instability stemming from medicine shortages, delays in production and vaccine rollout for political reasons and the resulting increase in costs has perpetuated an environment marked by uncertainty, heightened economic risk, lack of trust in institutions and an urgent need to reassess national strategies in response to post-pandemic challenges. Moreover, it is essential to foster a broader debate on Brazilian industrial policy in order to ensure sustainable development.

V. Conclusions

Innovation has become an essential factor in the development of any economy. This is because innovation, in the form of new or substantially improved products or processes, is directly linked to growth, job creation and income. Research in this field is therefore essential, as development cannot occur without innovation.

The results of this study show that technological capability and innovation effort are positively associated with the number of manufacturing firms undertaking technological innovations. These findings support the broader literature, which identifies these variables as key explanatory factors in determining whether productive sectors are innovative.

Although the government support variable was positively correlated with the number of innovating firms, it was not statistically significant. This lack of significance suggests that, during the period analysed, financing and innovation support mechanisms were not decisive in encouraging firms to innovate. This is mainly because financial support from the government is limited to certain sectors and firms and lacks a clearly defined mission, thereby allowing resources to be allocated to activities not directly related to innovation.

In this context, following the relative stability in product and process innovation rates in previous periods, the innovation capacity of Brazil's manufacturing industry remains far below desired levels. The 2017 PINTEC average innovation rate of 33.6% —a decline of 2.4 percentage points from the previous three-year period— illustrates this shortfall, as does Brazil's ranking of fifty-seventh in the 2021 Global Innovation Index.

Lastly, the study has several notable strengths, including the dependent variable indicator (innovations that are genuinely pioneering for the national industrial sector) and the econometric method applied. No other work in the related literature was found to use this combination of indicator and methodology. However, the small sample size limited the analysis, preventing an examination of how regional factors influence the emergence of innovations. Future research should incorporate this dimension into the model, allowing for a more in-depth study of firms in the sector and the application of alternative approaches, such as multilevel models.

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