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RETURN ON INVESTING IN INNOVATIVE ACTIVITIES: THE BRAZILIAN MANUFACTURING INDUSTRY

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ABSTRACT

Objective of the study: This study analyses the relationship between innovation investment and the number of firms that innovate in various sectors of the Brazilian manufacturing industry.
Methodology/approach: The estimated multiple linear regression model with panel data based on triennial investments covering 1998–2017 was considered.
Originality/Relevance: This study indicates that investment in R&D, both internal and external, does not influence the number of companies that have implemented certain types of innovation.
Main results: Investment in training and machinery/equipment acquisition showed a positive and significant relationship with the number of companies implementing some type of innovation in the analyzed sector.
Theoretical/methodological contributions: These findings contribute to better management of resources spent on innovation activities while filling a theoretical gap in the impacts of different innovative activities, considering the Brazilian manufacturing industry.
Social/management contributions: The return on innovation investment is uncertain in the organizational context. Understanding the return on investment in innovation activities contributes to decision-making regarding resource allocation, especially in organizations with financial constraints.

Keywords: innovation, investment, technological innovation.

RESUMO

RETORNO DE INVESTIMENTO EM ATIVIDADES INOVADORAS: UMA ANÁLISE DA INDÚSTRIA DE TRANSFORMAÇÃO BRASILEIRA

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Objetivo do estudo: Nesse estudo analisa-se a relação entre investimentos em inovação e o número de empresas que inovam em setores da indústria de transformação brasileira.
Metodologia/abordagem: Foi considerado o modelo de regressão linear múltipla, estimado com dados em painel, baseado em investimentos trienais, abrangendo o período de 1998 a 2017.
Originalidade/Relevância: O estudo indica que o investimento em P&D, tanto interno quanto externo, não influencia o número de empresas que implementaram algum tipo de inovação.
Principais resultados: O investimento em treinamento e aquisição de máquinas/equipamentos apresentou relação positiva e significativa com o número de empresas que implementaram algum tipo de inovação no setor analisado.
Contribuições teórico-metodológicas: Esses resultados contribuem para uma melhor gestão dos recursos investidos em atividades de inovação, ao mesmo tempo em que preenchem uma lacuna teórica sobre os impactos de diferentes tipos de atividades inovativas, tendo como referência a indústria de transformação brasileira.
Contribuições da sociedade/gestão: O retorno do investimento em inovação apresenta elevado nível de incertezas no contexto das organizações. Compreender o retorno do investimento em atividades de inovação de forma comparativa contribui para a tomada de decisão sobre a alocação de recursos, principalmente em organizações com restrições financeiras.

Palavras-chave: inovação, investimento, tecnologia.

RESUMEN

RETORNO DE LA INVERSIÓN EN ACTIVIDADES INNOVADORAS: UN ANÁLISIS DE LA INDUSTRIA MANUFACTURERA BRASILEÑA

Objetivo del estudio: Esta propuesta de estudio es analizar la relación entre la inversión en innovación y el número de empresas que innovan en sectores de la industria manufacturera brasileña.
Metodología/enfoque: Se ha considerado el modelo de regresión lineal multiple, estimado con datos de panel, basado en inversiones trienales, que abarca desde 1998 hasta 2017.
Originalidad/Relevancia: El estudio indica que la inversión en I+D, tanto interna como externa, no influye en el número de empresas que han implantado algún tipo de innovación.
Principales resultados: La inversión en capacitación y adquisición de maquinaria/equipo mostró una relación positiva y significativa con el número de empresas que implementaron algún tipo de innovación en el sector analizado.
Contribuciones teóricas/metodológicas: estos resultados contribuyen para una mejor gestión de los recursos gastados en actividades de innovación, mientras llenan un vacío teórico sobre los impactos de diferentes tipos de actividades innovadoras considerando como referencia la industria manufacturera brasileña.
Contribuciones de la sociedad/gerencia: el retorno de la inversión en innovación es incierto en el contexto de las organizaciones. Comprender el retorno de la inversión en actividades de innovación de manera comparativa contribuye a la toma de decisiones sobre la asignación de recursos, especialmente en organizaciones con restricciones financieras.

Palabras llave: innovación, inversión, tecnología.

1 INTRODUCTION

Investments in innovation are expected to result in new products and processes that can contribute to greater competitiveness and economic growth in the long term (Tajaddini & Gholipour, 2021). However, investing in innovation involves intangible assets with a high degree of uncertainty of return within the organizational scope (Hall et al., 2016; Lahr & Mina, 2020).

Investments in innovative activities are often irreversible, making such investment riskier than others (Hall, 2002). Furthermore, return on innovation, by its nature, is distributed over a very long period, which makes the organization rethink its resource allocation strategies (Tajaddini & Gholipour, 2021).

Thus, assessing the performance and return on investment in innovation so that organizations focus their efforts on more relevant projects, especially in times of financial crisis and uncertainty, is relevant. Research shows different behaviors of willingness to invest in innovative activities during periods of financial constraints or economic uncertainty. Hence, understanding the return on innovation investment in a comparative manner benefits decision-making on innovation resource allocation, especially in organizations with financial constraints (Vrchota & Řehoř, 2019).

Prior studies have provided mixed findings. Some studies argue in favor of a positive relationship between investment in innovation activities and innovation output (Rammer & Schubert, 2018; Baumann & Kritikos, 2016; Pellegrino & Savona, 2017; Hottenrott & Richstein, 2020; Michaelis & Markham, 2017), whereas others argue that the level of innovation investment does not interfere with their results (García-Quevedo et al., 2018; Oliver-Espinoza & Stezano, 2021; Audretsch & Belitski, 2020).

In addition to divergence, the literature analyzes the impact of each type of investment on innovation activities in detail. Khan et al. (2016) studied only the impact of research and development (R&D) investments and found that organizations with financial constraints were more sensitive than those without financial constraints. García-Quevedo et al. (2018) studied only the impact of R&D investments. Oliver-Espinoza and Stezano (2021) and Audretsch and Belitski (2020) were even more restrictive and observed the impact of investment only in internal R&D.

Despite the relevance of studies on the impacts of innovation investments, the literature still lacks comparative studies investigating the impact of innovative activities on innovation production using indicators and their relationships. This study analyzed the relationship between innovation investment and the number of companies that innovate in the Brazilian manufacturing industry. Based on the literature, four hypotheses were proposed for testing after analyzing the results.

Data from the Innovation Survey (PINTEC, in Portuguese: *Pesquisa de Inovação*), conducted by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese: *Instituto Brasileiro de Geografia e Estatística*), on the amounts invested in internal and external R&D, machinery/equipment acquisition, and training, as well as data on the number of companies that implemented some type of innovation from 1998 to 2017, were used. Data were arranged triennially. After collection, a multiple linear regression model with panel data was used to analyze the relationship between innovation investment and the number of innovative companies in Brazil's manufacturing industry sectors.

The analyses make it possible to fill a gap in the literature by understanding the impact of different types of investment in innovation (internal and external R&D, equipment, and training) on innovation in the Brazilian industry. As these are four synergistic activities, an aggregated and detailed analysis of investments in innovation is important to better diagnose innovative capacity (Santos et al., 2012).

The results contribute to a better understanding of the dynamics of innovation investment and how they reflect innovation, in addition to allowing for the identification and comparison of the results of different types of innovation activities in the context of the Brazilian manufacturing industry. This diagnosis allows organizational sectors to develop a better strategy for allocating resources in innovative activities, achieving greater efficiency in the production of innovation.

2 THEORETICAL BASIS

2.1 Innovation process

Innovation is an idea, policy, or technology adopted by an organization that is perceived as new by the unit and its users, even if it has already been used in another organization (Rogers, 2003), or in another context (Desveaux et al., 2019). Thus, innovation can be seen as a way of doing things differently, introducing technological change, opening new markets, improving material handling, and creating new organizations (Schumpeter, 1939).

The innovation process encompasses the development of innovative activities to launch new (or significantly improved) products or processes, including research and development, training, and the acquisition of machinery and equipment (OECD, 2005). Discussion on returns on investment in these innovation activities, as described in the Oslo Manual, is infrequent in the literature.

Within the innovation process, research analyzing investments in innovation activities generally focuses on capital investment issues rather than expenditures related to intangible innovative activities, such as internal research and development (Khan et al., 2016).

Additionally, Cook et al. (2019) emphasized that the capacity of the innovation process to generate results is related, among other factors, to the efficiency of decision-making and the information environment (which can reduce information asymmetry between managers and stakeholders).

2.2 Uncertainties in the innovation process

Innovation activities have unique characteristics that determine an organization's investments. According to Hall et al. (2016), projects aimed at innovative products are risky because of the uncertainty of both their results and demand. It is not known whether the innovative process will result in innovations that reach the market. This type of investment tends to be uncertain and irreversible, which makes investing in innovation riskier than in other types of investments (Hall, 2002). Furthermore, the returns on investments to produce innovation are spread over a very large period, which increases the payback time (Tajaddini & Gholipour, 2021).

Bhattacharya et al. (2017) reported that some innovation outcomes declined significantly one year after moments of uncertainty in the 43 countries that they analyzed. This uncertainty reduces incentives for innovation, with an even greater impact on sectors that are more dependent on innovation.

Some studies have demonstrated that investments in innovation are risky and conditioned by several factors. According to Wen et al. (2022), the uncertainty of return on investment in innovation is based on operational risk, projected profitability for the company, and the level of maturity of the responsible sector in R&D and sufficiency.

In this context of uncertainty, investments in R&D, for example, must be as assertive as possible, for greater efficiency in the allocation of resources. This assertiveness is observed in companies with greater technological maturity (Rocha et al., 2015). On the other hand, when investing in R&D activities, organizations with less technological maturity raise opportunity costs and reduce the effectiveness of results, as there is greater competition for available resources (Coad, 2011).

Contrary to the caution of investing in innovative activities in the face of uncertainty, Tajaddini and Gholipour (2021) demonstrated that the higher the economic uncertainty, the higher is the R&D expenditure per capita as well as the innovation results, as measured by patent applications, patent grants, and trademark applications.

Similarly, uncertainty can stimulate spending on innovative activities in organizations (Stein & Stone, 2012). Evidence in markets with low competition where large companies predominate shows that spending on innovative activities is also high in scenarios of greater uncertainty and large companies (Czarnitzki & Toole, 2013).

Investment strategies for innovative activities may vary according to an organization's business structure. According to Poyago-Theotoky (1998), private companies reduce investments in R&D under conditions of uncertainty (economic, political, or social), whereas public companies tend to spend relatively more on R&D under the same conditions.

Despite the inherent uncertainties in investments, innovation is fundamental for a company to adapt to the environment and ensure the continuity of long-term operations (García-Quevedo et al., 2018). Because innovating is crucial for the survival and success of companies, it is necessary to assess performance and return on innovation investment for organizations to focus their efforts on more relevant projects, especially in periods of financial crisis and uncertainty (Vrchota & Řehoř, 2019).

2.3 Innovation investments

Innovation investments can respond differently depending on the scenario. According to Nick Bloom et al., (2007), costs inherent to investments in knowledge, unlike capital and labor costs, can change as the new knowledge generated from R&D changes. According to the authors, the dynamism of the process, with a consequent lag in the results of investments in innovation, tends to discourage this practice.

Another phenomenon was observed in the opposite direction. If organizations cannot wait for an opportune and safe time to invest in innovation, whether due to the urgency of patenting an idea or launching a new product, postponing the decision to invest in innovative activities will have a high cost (Bloom, 2014).

Innovation investments can also lead to higher long-term profits in the long run. As long as they are encouraged by specific and constant policies, organizations can adapt innovation techniques to maximize profits over time. Otherwise, organizations continue to innovate (Knack & Keefer, 1997). In this sense, a product that is significantly improved demands investments in innovative activities before its implementation and introduction into the market, as recommended by the Oslo Manual, developed by the OECD (2018) and discussed by Lanz and Tomei (2016). Innovation output results from innovation production and its introduction into the market, the typical measures of which are the number of innovations or the number of firms that introduced innovations (Janger et al., 2017). In this sense, the literature is inconclusive when analyzing the relationship between innovation investment and innovation production. According to Rammer and Schubert (2018), investment restrictions on innovation activities directly influence the launch of new products and processes. According to the authors, reducing investment in innovation can be a good strategy in the short term, saving costs. However, over time, companies can lose their market positions if they do not continuously innovate to improve their products and processes.

Similarly, Khan et al. (2016) found that different financial realities impact the financing of innovation activities. Organizations with financial constraints are more sensitive to R&D investments than companies without severe financial constraints. In addition, the dynamics of investment in innovative activities vary according to a company's technological maturity.

In contrast, García-Quevedo et al. (2018) argued that although financial constraints generally increase the chances of abandoning innovation projects, they do not necessarily imply lower efficiency of the innovation process. For the authors, financial constraints on innovation can have a positive effect on survival, in that more efficient projects are chosen while a cash balance is established. Despite these conclusions, the authors highlighted only R&D factors and not the impact of investment in different types of innovation activities.

Innovation investment can be derived from internal or external R&D, training, or the acquisition of equipment and machinery. In general, the literature individually analyzes the impact of each type of investment in innovation activities, as discussed in the next section.

2.4 R&D investments

A particularity of R&D investment is that costs are embedded in specialized labor, and part of the aggregated knowledge is incorporated into hired professionals. Thus, for this knowledge to remain internalized within the organization, those involved in the operationalization of research must continue working in the organization, which is often a challenge and demands increasing investments in scale (Hall et al., 2013).

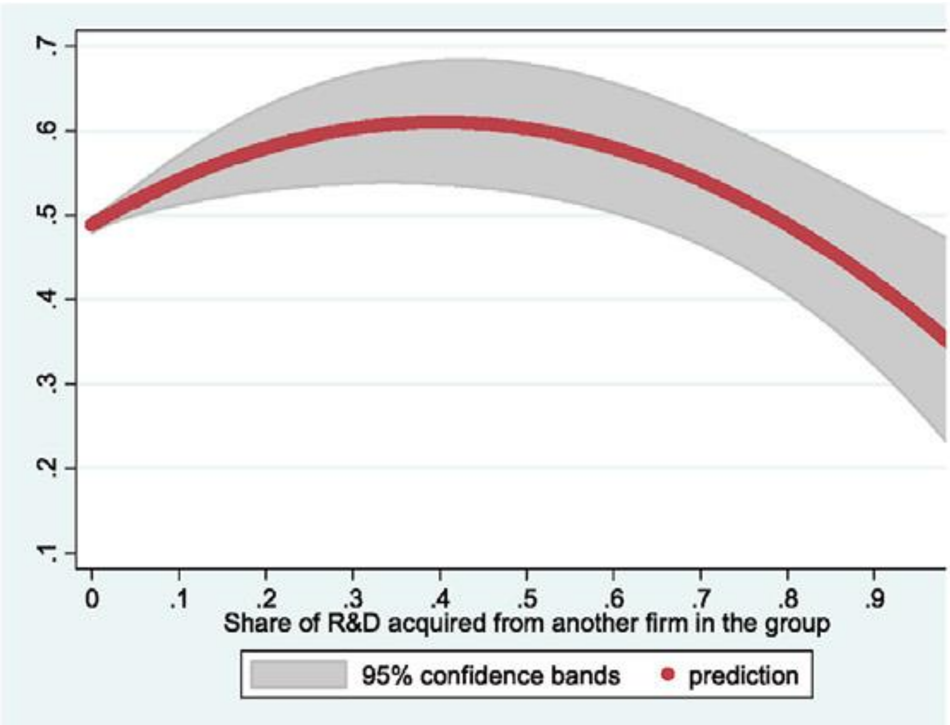
Oliver-Espinoza and Stezano (2021) and Audretsch and Belitski (2020) have pointed out that investments in internal R&D are not decisive for innovation results. According to them, not every company that invests in or receives financial support for R&D can innovate.

Conversely, Baumann and Kritikos (2016), Pellegrino and Savona (2017), and Hottenrott and Richstein (2020) have reported a positive relationship between R&D investment and innovation, especially in product innovation (Baumann & Kritikos, 2016). This investment is further optimized when there is funding from a combination of loans and grants (Hottenrott & Richstein, 2020). According to Pellegrino and Savona (2017), public policies that provide financial support for R&D aim to stimulate greater market competition and demand for innovation.

Carboni and Medda (2021) argued that external R&D acquisition increases the level of innovation up to a certain point, both to launch and sell innovative products. However, beyond a certain threshold, the negative effect of R&D outsourcing on innovation output increases. This means that acquiring external R&D reflects an inverted U-shaped behavior regarding innovation production.

Figure 1

External R&D and the propensity for product innovations



Source: Carboni and Medda (2021).

Figure 1 illustrates innovation production as a function of external investment in R&D. External sources, such as other companies in the group, universities, R&D centers, and consultancies, increase the probability of companies innovating, but after a certain limit, negative effects start to emerge on innovation performance (Carboni & Medda, 2021).

H1: Investments in internal R&D are decisive for the production of innovation

H2: Investments in external R&D are decisive for the production of innovation

2.5 Training investments

Investing in staff training contributes to creating an innovation culture in the company, with employees having skills focused on creating and implementing new products and services and a broader understanding of the innovation investment implemented by the organization (Michaelis & Markham, 2017). Innovative results are achieved, especially in smaller companies, through increased investments in employee qualifications and training of employees (Audretsch et al., 2020). However, these studies do not explore the extent to which investment in staff training contributes to innovation compared to other innovative activities. According to Hervas-Oliver et al. (2010), internal sources of innovation, such as investment in internal R&D and consequently training, have a greater contribution in organizations focused on product innovation than in organizations focused on process innovation. Robertson and Patel (2007) argued that organizations that invest little in training activities for their employees also produce less innovation. Therefore, a significant and direct relationship exists between investment in training and innovation production.

Particularly in the Brazilian industry, investments in training are generally associated with other innovative activities and are relatively low. This may explain the difficulties faced by Brazilian industry in developing innovative products and processes (De Campos et al., 2018)

H3: Investments in training are crucial for the production of innovation

2.6 Machines and equipment investments

In addition to internal investment in the production of innovations, the process can also be characterized by the acquisition of equipment or machines from other organizations that are internalized for the development of new products, processes, or services.

Machines and equipment investments are generally characterized by low technology and low value-added companies, which depend on the acquisition of knowledge developed in other organizations (Rammer et al., 2009). Hervas-Oliver et al. (2010) compared the effects of investments in internal and external R&D, training, and machine acquisition. For the authors, external innovation sources, such as acquiring machines, equipment, and software, are more responsible for innovation production in processes than in products.

Similarly, Strachman and Avellar (2008) stated that machines and equipment are crucial for technological learning and the development of innovations in products and processes in organizations.

In this sense, investments in the acquisition of equipment and machinery help to disseminate technical progress, which catalyzes innovations and makes the organization grow in productivity (Araújo, 2011).

H4: Investments in the acquisition of machinery and equipment are crucial for the production of innovation

3 METHODS

3.1 Research design

Supported by related literature, this study analyses the relationship between innovation investment (divided into internal and external R&D, training, and equipment acquisition) and the number of companies that innovate within a given case study area of the manufacturing industry in Brazil.

This is a theoretical-empirical study with a quantitative approach based on a statistical analysis of the data collected. As for the research strategy, data records in secondary databases were used to test the relationship between the predictor variables and the dependent variable (Saunders et al., 2007).

A multiple linear regression model with panel data was used to analyze the relationship between innovation investment and the number of innovative companies in the Brazilian manufacturing sector. This method is based on the researcher being allowed to incorporate the differences in behavior between notes over time into the model, capturing effects not directly detectable in the variables, such as technological changes, macroeconomic changes, and government incentives, which are considered constant over the analysis period (Greene, 2012).

3.2 Data and sample collection

PINTEC's data come from a survey carried out by the IBGE, whose reference is the Oslo Manual, to build indicators that can measure innovation in organizations installed in Brazil at the sectorial, national, and regional levels. These data include information on innovation activities, funding sources, R&D activities, cooperation for innovation, government support, and other innovation methods (IBGE, 2022).

Innovation can be characterized as an abstract phenomenon that is difficult to measure. Therefore, the sampling and choice of the base aim to increase the reliability of the results using innovation indicators that can reflect the stratum of potentially innovative activities and companies as faithfully as possible.

Innovative activities are necessary for the development and implementation of new or significantly improved processes and products (OECD, 2018). The following are distinguished in PINTEC:

a) Internal (R&D: An activity that features an unprecedented element and resolution of a scientific and/or technological problem, encompassing basic research, applied research, and experimental development.
b) External R&D: An activity decentralized to other organizations that conduct R&D activities that are later internalized.
c) The acquisition of machinery and equipment aims to implement new products and processes with the possibility of improving technological performance or becoming a means of implementing new products.
d) Training: Knowledge activities aimed at the development of new products and processes.

According to (OECD, 2018), these innovative activities can influence the organizational ecosystem in different ways. Depending on the innovations introduced in the market, the results of innovative activities and billing can be changed, new markets can be developed, impacts on the environment can be reduced, and products and processes can even be safer.

The variables were obtained from the Innovation Research (PINTEC) Database of the Brazilian Institute of Geography and Statistics (IBGE). The data were tabulated in a panel format with the sectors of the Brazilian manufacturing industry forming notes and triennial time units corresponding to seven periods: 2000, 2003, 2005, 2008, 2011, 2014, and 2017.

To achieve a balanced panel that includes all units with notes available throughout the period (Greene, 2012), 28 sectors in the Brazilian manufacturing industry remained in the database throughout the time series. The total number of notes was 196, resulting from the analysis of 28 industry sectors in seven periods.

3.3 Data analysis

To analyze the relationship between investment in innovation and the number of innovative companies in the Brazilian manufacturing industry, a multiple linear regression model with panel data was estimated. Equation 1 expresses the multiple linear regression representation adopted from the panel data.

$$IC_{it} = \alpha + \beta_1 ReDext_{it} + \beta_2 ReDint_{it} + \beta_3 MEQ_{it} + \beta_4 TR_{it} + \varepsilon_{it} \quad (1)$$

where IC is the number of companies that implemented innovations, ReDext is the amount spent on external R&D, in *BRL*, ReDint is the amount spent on internal R&D, in *BRL*, MEQ is the amount spent on machinery/equipment acquisition, in *BRL*, TR is the amount spent on training, in *BRL*, *i* is the manufacturing industry sector, *t* is the period analyzed, α is the constant intercepting the regression line, *β* is the angular coefficient per variable, and *ε* is the random error.

The main objective is to obtain statistical explanations for the number of firms that have implemented innovation in each sector of the Brazilian manufacturing industry. All the variables were generated directly from the database. To achieve the outlined goals, three analysis models were estimated: pooled, random, and fixed effects. Subsequently, to choose the most adequate model, the following tests were used: F-Test, to decide between the pooled and fixed-effects models; Breusch–Pagan Test, to decide between the pooled and random-effects models; and the Hausman test, to decide between the fixed and random-effects models.

4 RESULTS

The amounts invested in innovation from 2015 to 2017 in each sector of the Brazilian manufacturing industry are shown in Table 1 for each innovative activity: internal R&D (investments in R&D carried out within each company), external R&D (investments in R&D developed in another organization and internalized by the company), machinery and equipment (acquisition of machinery and equipment developed by another organization), and training (investments in personnel training).

Table 1

Brazil's manufacturing industry sectors and investment for the triennium 2015 – 2017

Manufacturing Industry Sectors	2015-2017			
	Internal R&D ($BRL.10^6$)	External R&D ($BRL.10^6$)	Machinery/ equipment ($BRL.10^6$)	Training ($BRL.10^6$)
Manufacturing of food products	1,133.95	71.80	3248.97	206.62
Manufacturing of beverages	92.57	7.70	448.21	11.14
Manufacturing of tobacco products	0.00	0.00	13.90	0.50
Manufacture of textile products	52.33	1.75	191.85	4.02
Manufacturing of clothing and accessories	91.35	1.18	364.54	11.93
Preparation of leather and manufacturing of leather goods, travel goods, and shoes	254.90	5.74	104.49	5.86
Manufacturing of wood products	0.00	0.00	279.12	3.56
Manufacturing of cellulose and other pulps	82.06	20.36	64.51	0.37
Manufacturing of paper, packaging, and paper products	220.48	2.73	763.65	8.35
Publishing, printing, and reproduction of recordings	17.43	4.99	125.54	13.64
Manufacturing of coke, alcohol, and nuclear fuels	1,977.54	460.79	1034.06	6.67
Petroleum refining	1,856.95	0.00	21.84	3.29
Manufacturing of chemical products	1,919.58	1,294.32	792.36	33.88
Manufacturing of pharmaceutical products	1.497.85	0.00	162.17	16.70
Manufacturing of rubber and plastic products	518.49	188.60	953.93	39.45
Manufacturing of non-metallic mineral products	418.41	13.66	483.69	11.53
Steel products	518.69	23.61	531.19	3.69
Non-ferrous metals and foundry	115.66	25.04	194.01	3.08
Manufacturing of metal products	218.77	30.88	840.15	30.09
Manufacturing of machinery/equipment	78.15	38.00	120.20	1.77
Manufacturing of office machinery and computer equipment	202.65	239.04	12.59	0.77
Manufacturing of machinery, apparatus, and electrical material	699.77	44.46	371.68	23.27
Manufacturing of basic electronic material	842.37	36.13	495.94	55.89
Manufacturing and assembly of motor vehicles, trailers, and bodies	2,483.77	300.42	1565.47	36.23
Manufacturing of vehicle parts and accessories	992.13	83.58	563.58	24.32
Manufacturing of other transport equipment	2,322.23	0.00	461.27	12.44
Manufacturing of furniture pieces	112.64	3.00	369.29	9.11
Manufacturing of diverse products	134.53	13.84	174.76	13.88

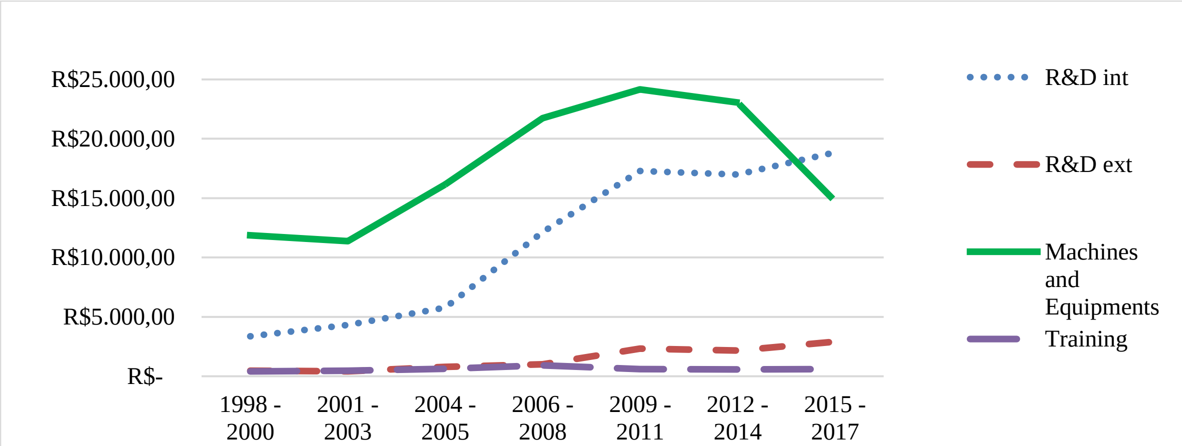
Source: Pintec (2021).

According to Table 1, the largest expenditures on innovative activities in BRL are in manufacturing food products, which invest in equipment and machinery; manufacturing and assembly of motor vehicles, trailers, and bodies, which invest in internal R&D, and manufacturing of chemical products, which invest in external R&D.

First, we observed the evolution of investment in innovative activities over time. During the period analyzed, between 1998 and 2017, investments mostly increased in all innovative activities, with machinery/equipment acquisition as the main recipient of resources during the period, except for the last triennium (2015 to 2017), as shown in Figure 2.

Figure 2

Investment in internal and external R&D, machinery/equipment, and training – 1998 to 2017 (BRL.10^6)



Source: Research data.

According to Figure 2, the amount spent on training and the acquisition of external R&D remained below the amount spent on internal R&D and the acquisition of machinery and equipment throughout the analyzed period.

To verify the assumptions of the regression model, the Jarque–Bera test was performed to verify the normality of the residuals. The statistical result was 235.3, with an associated p-value of 0, which was not significant at a critical value of 5%. A variance inflation factor (VIF) test was performed to verify the correlation between the explanatory variables. Table 2 presents the VIF test results.

Table 2

VIF test

Variable	VIF
ReDext	1,67
ReDint	1,88
MEQ	1,75
TR	1,75

Source: Author's elaboration (2021).

To achieve the research objectives, tests were conducted to choose the most appropriate model among pooled, fixed effects, and random-effects models. The F-Test found a significant p-value, rejecting the null hypothesis of no individual differences, where the fixed-effects model is recommended over the pooled model. The Breusch–Pagan test also showed a significant p-value, rejecting the null hypothesis of no random effects, with the random-effects model being more recommended than the pooled model. The Hausman test also indicated a significant p-value, rejecting the null hypothesis of no difference between the fixed and random-effects models, with the fixed-effects model recommended. Considering fixed effects, this model is the most appropriate for this type of analysis. Table 3 presents the test results and estimators.

Table 3

Test Results and Estimators

	Pooled	Fixed effects	Random effects
External R&D Investment	0.130 (0.25)	0.0119 (0.03)	0.0188 (0.05)
Internal R&D investment	-0.527*** (-4.86)	0.152 (1.53)	0.0946 (0.95)
Investment in machinery/equipment	0.873*** (8.77)	0.740*** (7.75)	0.748*** (8.02)
Training investment	9.303* (2.05)	8.682*** (4.24)	8.597*** (4.16)
Constant	582.5*** (5.77)	412.8*** (5.65)	432.3* (2.29)
N	196	196	196
R^2	0.3611		
R-sq within		0.4381	0.4366
R-sq between		0.2228	0.2396
R-sq overall		0.2680	0.2816
F-test	25.22***		
Breusch–Pagan test	281.57***		
Hausman test	21.84***		

Source: Author's elaboration (2021)
T Statistics in brackets
*p<0.05 **p<0.01 ***p<0.001

Despite not being the most appropriate model according to the statistical tests, the pooled model showed a negative and significant impact of investments in internal R&D on innovation, which was not observed in the other models. This means that the impacts, whether significant or not, were all positive, except for investments in internal R&D in the pooled model.

The results of the fixed-effects model show no statistical significance in R&D investment, either internally or externally, for the number of firms that implemented innovation. This finding implies that there is no significant association between the amount invested in R&D and the number of companies that innovate in the Brazilian manufacturing sector.

By contrast, investment in machinery/equipment acquisition and training presented statistically significant results and a positive relationship with the number of companies that innovate within each sector of the Brazilian manufacturing industry.

The results highlight that the innovation activities of equipment and machinery acquisition and training in the Brazilian manufacturing industry contribute most to the number of companies implementing innovation. Investment in training is even more efficient: for every BRL 1,000.00 invested, 8.68 new companies implement some type of innovation, while with the same amount invested in machinery/equipment acquisition, a smaller number of new companies (0.74) innovate.

5 DISCUSSION

In Brazil, as demonstrated by the evolution of the amount invested in innovative activities, there is a large number and amount investment in purchasing machinery and equipment, including state support from the BNDES (FAPESP, 2011), while European countries concentrate on greater spending on domestic research and development (OECD, 2005). This phenomenon provides evidence of how innovation flows, mostly starting in developed countries and returning to developing countries, in the form of machines and equipment with high added value.

The descriptive analysis also shows a growing increase in investments in innovative activities, although, for the last period of analysis, investments in the acquisition of machinery and equipment have declined compared to the last period.

The results of the multiple linear regression analysis corroborate the findings of Oliver-Espinoza and Stezano (2021) and Audretsch and Belitski (2020), who demonstrated that the level of investment in R&D does not determine innovation results. Therefore, the findings do not support Hypotheses 1 and 2, which predicted the influence of R&D investment on innovation production. Similar to the authors, this study found no evidence that investing in R&D can necessarily produce more innovation because of the non-statistical significance of both variables that indicate investment in internal and external R&D.

These results differ from those found by Baumann and Kritikos (2016), Pellegrino and Savona (2017), and Hottenrott and Richstein (2020), who found not only the influence of these investments on the production of innovation, but also a positive relationship between them, enhanced by funding and specific public policies.

As for the external acquisition of R&D, the results differ from those of Carboni and Medda (2021), who argued that although investments increase the level of innovation to a certain extent, there is a negative effect on the production of innovation: the greater is the outsourcing of R&D. Therefore, according to the authors, a determining factor exists for investment in innovation production.

On the other hand, investments in training also prove to be statistically significant for innovation production, supporting Hypothesis 3. In addition, Taveira et al. (2019) noted that investment in training and staff development has a greater relevance in innovation production than investment in R&D in emerging countries such as Brazil. A caveat regarding this result, demonstrated by the training variable, is that in many cases, these activities are associated with the purchase of machinery and equipment. These results are similar to those of De Campos et al. (2018) and Robertson and Patel (2007), who observe a significant and positive relationship between investments in training and innovation production.

Similarly, the results of the multiple linear regression analysis show that investments in the purchase of machinery and equipment have a positive and statistically significant relationship with the production of innovation, which supports Hypothesis 4. This finding is in line with that of Pivoto et al. (2018), who found similar results when studying agricultural innovations and concluded that Brazil has a greater tendency to adopt technological innovations from other countries than contribute to their development. The results are also similar to those of Hervas-Oliver et al. (2010), who did not distinguish between greater influences on product or process innovation. Generally, the results demonstrate that in the Brazilian manufacturing industry, the cheapest way to increase the number of companies that innovate is by investing in equipment and machinery acquisition and personnel training. This scenario highlights how Brazilian industry is dependent on foreign technology and has difficulty developing innovation internally.

On the one hand, the internal incapacity to develop innovations through R&D is worrying; on the other hand, a practical path is drawn: acquiring equipment and machines to introduce innovations in the internal market and incorporating staff training into industry routines. Incentive policies for the internal development of innovations through R&D and training should be adopted to improve the performance of these innovative activities in the long term, whereas, in the short term, incentive policies for machinery/equipment acquisition should be established for more companies in the manufacturing sector to innovate.

6 CONCLUSIONS

This study aimed to analyze the relationship between innovation investment and the number of firms that innovate to understand the behavior of innovation investment and compare their natures by analyzing how each influences innovation production.

The results of the statistical analysis show that neither internal nor external investment in R&D influences the number of companies that have implemented innovation in the Brazilian manufacturing sector. Conversely, investment in training and machinery/equipment acquisition has a positive and significant relationship with the number of companies implementing certain types of innovation.

In addition, our results show that a lower investment in training generates a larger number of firms implementing innovations than investments in machinery/equipment acquisition. However, investment in training was the lowest among the four types of innovation investments. This suggests that there is greater investment in training in the Brazilian manufacturing sector for more companies to implement product, process, or process innovation. Despite its contributions, this study has limitations, such as its database, the composition of which changed throughout the analysis. Another limitation is the analysis of industry sectors and not individual organizations, hampering the understanding of the particularities of each company. Additionally, the number of observations is relatively low, even though it is a panel of data. Another necessary caveat is that while all analyzed periods deal with trienniums, there is a concatenation of only two years, from 2004 to 2005, which may interfere slightly with the results. Additionally, our quantitative analysis does not allow us to understand how innovation is generated through investment in training.

Further studies should use a qualitative approach to understand why and how training, as an innovative activity, contributes to innovation. Furthermore, the behavior of organizations regarding innovation activities, particularly R&D, is subject to several factors that may hinder or enable their decision to invest in such uncertain activities. Therefore, future studies should assess the innovation ecosystem to enable a greater structural diagnosis of organizational constraints on innovation.

This study fills a gap in the literature on the impact of different types of innovation investments in the Brazilian industrial context through quantitative data analysis over a period of almost 20 years. In practice, the greater the evidence on this type of investment, the more efficient will be the results, which is relevant, especially in the context of the uncertainty inherent in innovation investments. This study provides an additional subsidy to guide the decisions of public and private actors when allocating resources for innovation.

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AUTHORS' CONTRIBUTIONS

Contribution	Oliveira, T.S.	Borges Júnior, C. V.	Caetano, M.
Contextualization	X	X	X
Methodology	X	----	----
Software	X	----	----
Validation	X	X	X
Formal analysis	X	X	X
Investigation	X	----	----
Resources	X	X	X
Data curation	X	----	----
Original	X	X	X
Revision and editing	X	X	X
Viewing	X	X	X
Supervision	X	X	X
Project management	X	X	X
Obtaining funding	-------	X	X

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