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Impact assessment of innovation tax incentives in Brazil

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Abstract

Purpose – This paper evaluates the effects of tax incentives on business innovation in Brazil that were established by Law 11,196/05 (the "Fiscal Incentives Law") to test whether they have had a positive impact on beneficiary firms' innovation input and output and on their performance.

Design/methodology/approach – The policy impacts are estimated using microdata on 13,706 firms available in the 2008 and 2011 editions of the Brazilian Innovation Survey (PINTEC) and by applying propensity score matching with difference-in-differences.

Findings – The results suggest a positive and statistically significant impact of the policy on research and development (R&D) expenditures (average of approximately US$ 264,000 in 2011), the number of research staff (average of five researchers) and total employment (approximately 5% of the beneficiary firms' mean size). However, no impact was found on the overall spending on innovative activities, the percentage of sales and exports from new products, net revenue or net revenue per employee.

Practical implications – The findings provide empirical support in favor of tax incentives as a policy tool to boost business innovation in the country. However, the absence of significant effects on innovative activities expenditures and on most indicators of innovation output and firms' performance reveals shortcomings of the policy that need to be addressed.

Originality/value – The study complements and advances the findings of previous studies by assessing policy impact on total innovative activities expenditures and on innovation output and firm performance.

Keywords Impact assessment, Brazilian innovation policy, Tax incentives

Paper type Research paper

1. Introduction

Governments have devised and adopted policies to foster business innovation since at least the second half of the 20th century (Bloom, Chennells, Griffith, & van Reenen, 2002). Since the 1990s, policymakers have become increasingly interested in tax incentives, and currently, many countries resort to tax incentives as part of their strategy to indirectly finance business innovation projects (EY, 2020). In line with this international trend, the Brazilian Congress

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approved Law 11,196/05 (the "Fiscal Incentives Law") in 2005, which established a new institutional framework for innovation tax incentives in the country. With the new law, the number of benefiting firms and the volume of tax waivers increased substantially (Brazilian Ministry of Science Technology and Innovation, 2016), thereby making these incentives the most important horizontal policy tool to foster innovation in the country.

Following international expansion, a substantial debate on the role and importance of tax incentives within innovation policies has been developed, with empirical studies in different countries dedicated to assessing and measuring their impacts. There is substantial evidence of the additionality effects of this policy tool on business research and development (R&D) investment (Hall, 2020), but there is less consensus on their effectiveness (Blandinieres, Steinbrenner, & Weiß, 2020; Hall, 2020). More recently, this research agenda has been expanded to investigate innovation output and firm performance (Dechezleprêtre, Einiö, Martin, Nguyen, & van Reenen, 2016; Nilsen, Raknerud, & Iancu, 2020), although these dimensions present additional difficulties for assessment and are therefore less studied (Ognyanova, 2017). In the case of Brazil, the contribution of the Fiscal Incentives Law to business innovation is still unclear because, to date, only a small group of studies using microdata and quantitative methods have investigated the effects of the benefits, and such analyses mostly focused on innovation inputs, such as R&D spending and technical research staff (Kannebley & Silveira Porto, 2012; Kannebley, Araújo, Maffioli, & Stucchi, 2013; Shimada, 2014).

Considering this gap, the aim of this study is to present a quantitative assessment of the impacts of the Fiscal Incentives Law on business innovation in the country for two sets of outcomes. First, the study investigates the input additionality of the policy by considering business investments in R&D and the overall spending on innovative activities expenditure and R&D staff. The impact of the policy is also estimated for innovation output and firm performance, which is measured as the share of sales from new products, the percentage of exports from new products, total employment growth, net revenue and net revenue per employee. The empirical analysis is based on microdata from the Brazilian Innovation Survey–PINTEC (IBGE, 2013), combined with the annual list of beneficiary firms of the Fiscal Incentives Law (Brazilian Ministry of Science Technology and Innovation, 2016) and the list of firms that engaged in international trade (Brazilian Ministry of Economics, 2017). Policy impact is estimated as the average treatment effect on the treated using propensity score matching (PSM) with difference-in-differences. The sensitivity of the results to hidden variable bias is tested through the Rosenbaum bounds approach.

This paper complements and contributes to previous studies on the Brazilian policy in two ways. First, policy impact is assessed not only on R&D spending but also on the bulk of innovative activities. This assessment is an important indicator by which to evaluate Brazilian tax incentives, as Brazilian law allows for the deduction of a wide range of investments that do not qualify as strict R&D. Additionally, it is a measure that reflects a broader perspective on business innovation strategies and investment (Hall, 2020) appropriate to the Brazilian case, as most national firms rely on an imitative strategy (Mazzucato & Penna, 2016). The second contribution of the paper is to assess the effects of Brazilian policy on innovation output and firm performance, thereby adding to the recent but still limited evidence presented in the international literature on this dimension of additionality (Nilsen *et al.*, 2020), which has been mostly neglected in previous analyses of the Brazilian policy.

The analysis also has practical implications for the debate on innovation policy in Brazil. The results indicate that the Fiscal Incentives Law has positively impacted R&D expenditures and the number of research staff of beneficiary firms; however, no significant effect has been found for total expenditures on innovation activities, thereby reinforcing the importance of investigating policy additionality in both categories of spending. A positive and statistically significant effect on employment growth was found but not on the percentage of sales and exports generated by new products, net revenue or net revenue per employee. The absence of an impact on most output and firm performance indicators suggests points of improvement in the design of these incentives.

The second part of the paper following this introduction reviews the literature related to innovation tax incentives and to impact assessment, summarizing the most important and frequent findings of existing research on the topic. The third part describes the institutional framework and presents a general overview of the Brazilian tax policy. The fourth section details the empirical research strategy, including the estimation method and data, and the fifth section presents and discusses the results of the study. The sixth and final section summarizes the paper and discusses the limitations of the findings.

2. Innovation tax incentives and impact assessment

The public financing of innovation activities and expenditures is supported by different economic theories. The presence of market failures renders private investment in this activity suboptimal, thus requiring additional public resources to supplement it (van Reenen, 2020). The main argument used to justify public financing of innovation is the limited appropriability of innovation results caused by knowledge spillovers; i.e. firms investing in or pursuing innovation can capture only partially the value of the knowledge resulting from these activities (Hall, 2020). Estimates indicate that the social returns of innovation may be approximately three to four times as large as the value of private returns (Lucking, Bloom, & van Reenen, 2019).

Within the context of innovation policy, tax relief is a form of discount, credit or special treatment granted by the government to firms with positive innovation spending or that are implementing innovation projects. These incentives can have different arrangements, such as credits, allowances, accelerated depreciation or amortization, and reduction or exemption of taxes levied on innovation inputs or outputs. Such policy tools were first introduced in the United States and Canada, but they have evolved and spread to many countries since then (Hall, 2020). In 2018, more than 80% of the member countries of the Organization for Economic Cooperation and Development (OECD) used some form of tax break for this purpose (van Reenen, 2020), and EY (2020) has listed 48 nations (both developed and developing economies) that have adopted a tax scheme that favors innovation and R&D-related activities. Not only are more countries employing this policy tool, but its use has also been intensified; tax incentives currently account for 55% of total government support for R&D and 0.1% of total gross domestic product (GDP) in the OECD countries, surpassing the percentage accounted for by direct funding (OECD, 2020).

Tax reduction affects firms' economic incentives and business strategies differently than direct funding. The main advantage of tax incentives is their "market-oriented" nature in the sense that the government does not decide the projects to be funded (Hall & van Reenen, 2000). Private decision-making and the allocation of resources are thus preserved, thereby reducing allocative distortions arising from government intervention. This type of incentive tends to reduce uncertainty, favoring long-term business planning (Hall, 2020).

However, the economic literature has also pointed to disadvantages of the fiscal approach. The leading downside is a possible crowding-out effect (Hall & van Reenen, 2000), which was found in earlier empirical studies (Zúñiga-Vicente, Alonso-Borrego, Forcadell, & Galán, 2014) but was rejected by recent analyses (Czarnitzki & Hussinger, 2018). Additionally, firms can declare unrelated activities or expenditures as R&D just to make them eligible under the policy, following the relabeling argument (Chen, Liu, Serrato, & Xu, 2018).

A large body of literature has analyzed and assessed tax incentives in several countries (for recent reviews, see Hall, 2020; and Lane, 2020). There is extensive evidence of the positive impact of tax incentives on R&D spending in both developed (Rao, 2016; Agrawal, Rosell, & Simcoe, 2020) and developing economies (Tian, Yu, Chen, & Ye, 2020; Ivus, Jose, & Sharma, 2021). In addition, incentives have also been found to increase R&D intensity (i.e. expenditures over sales; Ivus *et al.*, 2021), the growth rate of R&D (Tian *et al.*, 2020) and the size of R&D departments (Guceri, 2018).

There is less consensus, however, on the effectiveness of such incentives, which is usually measured by the elasticity of business R&D spending with respect to the reduction of the tax cost (i.e. the ratio of the amount of money invested in R&D to the amount saved with the tax break). Previous studies have found an elasticity lower than one (IFS, 2015), but more recent research has challenged this conclusion by suggesting that the additional investment of beneficiary firms in R&D is at least as large as the reduction of their taxes (Blandinieres *et al.*, 2020; Dechezleprêtre *et al.*, 2016).

It is also equally important to consider the effects that such incentives have on innovation and economic impact, i.e. output additionality. However, such dimension is more difficult to investigate because innovation cannot be measured directly (Hill, 2013) because the totality of beneficiaries is not easily tracked due to knowledge spillovers (OECD, 2015), and because of methodological difficulties in modeling the link between inputs and outputs (Gault, 2013).

Despite such challenges, a recent but small body of literature has been dedicated to assessing the output additionality of innovation tax policy (Nilsen *et al.*, 2020). Such studies have found evidence of the positive effects of tax incentives on different measures, such as the share of sales from new products (Czarnitzki, Hanel, & Rosa, 2011), patenting (Tian *et al.*, 2020; Ivus *et al.*, 2021) and the development of new products (Aralica & Botric, 2013). A firm's performance may also be positively affected by fiscal policies that promote innovation, thereby causing employment growth (Nilsen *et al.*, 2020), export growth (Freel, Liu, & Rammer, 2019) and more entrepreneurship (Fazio, Guzman, & Stern, 2019). On the other hand, such incentives do not seem to affect productivity (Nilsen *et al.*, 2020; Cappelen, Raknerud, & Rybalka, 2007), suggesting that this might constitute a limitation or challenge to be addressed in the design of these policy tools.

3. Horizontal tax incentives for innovation in Brazil: the fiscal incentives law

Brazil presents an innovation landscape of an emerging economy. It shares some features of technologically advanced countries, such as frontier research in a few areas (oil and gas, agriculture and health), along with a system of agencies devoted to promoting science and innovation (Mazzucato & Penna, 2016). At the same time, the country faces challenges similar to those experienced by less developed nations (Barrichello, Dos Santos, & Morano, 2020; Mazzucato & Penna, 2016), including a large informal sector, unskilled labor and little use of knowledge-based services (Santos, 2020). Gross R&D investment funded by the industry was only approximately 0.5% of the country's GDP in 2012, which was substantially lower than the share of 1.45% for OECD countries (OECD, 2016).

Since 2003, the debate on appropriate policies to foster business innovation has regained strength in the country. The Industrial, Technological and Foreign Trade Policy (PITCE) of 2003 tried to address the challenge of creating a business environment that encourages innovation without protectionism, thereby enhancing firms' technological capabilities and international competitiveness (Suzigan & Furtado, 2006). Three major industrial policy plans were issued by the federal government, and public outlays for R&D as a percentage of GDP increased from 0.51% in 2002 to 0.71% in 2013, similar to the average for OECD countries (OECD, 2016).

This industrial policy framework brought tax incentives to a more central position in the innovation policy debate. The Congress approved the Fiscal Incentives Law in 2005, which not only expanded previous incentives but also improved the procedures to facilitate participation in the policy and reduce operational costs (Avellar & Oliveira, 2009). The new law altered the landscape of the country's innovation policy mix by raising the share of tax incentives in government support for R&D from less than a quarter in 2004 to approximately a third in 2014 (Brazilian Ministry of Science Technology and Innovation, 2015). During the early years of the law (2006–2009), innovation investment and tax incentives grew sharply, although both indicators experienced a decrease in the subsequent period (Brazilian Ministry of Science Technology and Innovation, 2016).

The most relevant incentive provided by the law is the enhanced deduction of innovation expenditures from the taxable base of income tax and social contribution on net income, i.e. CSLL (Kannebley & Silveira Porto, 2012; Araújo, 2010). Firms deduct up to 160% of their investment, and this rate can increase to 200% if new researchers are hired and expenditures are related to patented products (Calzolaio & Dathein, 2012). The incentives are volume-based, i.e. calculated based on all qualified innovation expenditures, as opposed to the incremental scheme adopted in the United States, Turkey and Mexico, in which firms can only deduct the amount exceeding a predefined baseline (OECD, 2020). Firms may also benefit from accelerated depreciation and amortization for the purchase of new equipment and technology, along with a 50% reduction of the tax for industrialized products (IPI) rate. Finally, they are also exempted from withholding income tax on any international payments for the registration of intellectual property.

The law defines innovation as any new or improved product or manufacturing process that enhances productivity or increases competitiveness (following closely the definition of business innovation adopted internationally by the new Oslo Manual; OECD & Eurostat, 2018). Deductible expenses are all labeled as "research and development" (Kannebley & Silveira Porto, 2012), although such a concept actually encompasses a far broader range of activities than the "strict R&D" defined in the mentioned international references. Decree 5,798/06 states that deductible expenses include basic and applied research, experimental development, basic industrial technology and technical support services. Such a broad definition is advantageous to countries that are not on the technological frontier, as it rewards a broader concept of innovative activity than just R&D (Hall, 2020) and helps the industry catch up faster by using and imitating foreign technology (IFS, 2015).

The law does not clearly state the requirements for firms to benefit from the tax incentives. Considering only the deductibility of expenses, the minimum eligibility requirements are (1) to operate under the real profit tax regime, (2) tax clearance, (3) positive innovation expenditures during the fiscal year and (4) taxable income in the same fiscal year (the law does not provide for deduction of expenses in subsequent or previous years).

Unlike the United Kingdom, the United States and other countries (OECD, 2020), Brazil does not adopt any favored treatment for small enterprises. The policy design actually makes it more difficult for small firms to benefit from the incentives as the requirement that companies operate under the real profit tax regime work as an entry barrier (Calzolaio & Dathein, 2012). Pursuant to Brazilian tax legislation, small firms (yearly gross revenue of up to 78 m Brazilian *reais*, according to Law 12,814/2013) can opt for the presumed profit or the SIMPLES (Special Unified Collection System for Taxes and Contributions owed by Micro and Small Enterprises) regimes. In such cases, the law assumes a percentage of the revenue to be considered profit for tax purposes. As these schemes are based on a presumed tax base, regulations expressly forbid these companies to benefit from any tax deduction (Decree 3.000/99, art. 526; and art. 19 of Normative Instruction SRF 608/06), including those provided for in the Fiscal Incentives Law. To understand how restrictive such requirements are within the Brazilian context, in 2018, only 1.38% of the companies in the country opted for the real profit tax regime (Brazilian Federal Revenue Office, 2020).

The reduction in the marginal cost of R&D (measured by the "*b-index*"; OECD, 2020) due to the incentives is estimated to be approximately 8% (Araújo, 2010). The deductibility of R&D expenses represents the largest bulk of incentives petitioned by firms; approximately 74% of the benefits come from the income tax deduction, 26% come from the CSLL deduction, and less than 1% come from the reduction of the IPI. Beneficiary firms operate in different industrial sectors, but the main beneficiaries are the transport equipment, software, chemical/petrochemical and electronics industries (Brazilian Ministry of Science Technology and Innovation, 2016).

To date, only a few studies using microdata and quantitative or quasi-experimental methods have investigated and assessed the results of tax incentives for innovation of the Fiscal Incentives Law, presenting evidence of policy additionality on both innovation input and output indicators. The incentives were found to have a substantial effect of 86 to 108% on R&D spending, along with a positive impact on technical research staff (Shimada, 2014). There is also evidence that the policy affects firm size and exports per employee and generates spillovers due to labor mobility, but the effect on labor productivity is unclear (Kannebley *et al.*, 2013). The empirical analysis presented in the next section adds to this existing evidence and assesses the policy impact on additional innovation input and output indicators that are relevant for discussing the role of the policy in the Brazilian industrial context and for identifying areas of improvement of the policy.

4. Empirical analysis

The impact of the tax incentives provided by the Fiscal Incentives Law was estimated using microdata on Brazilian firms and by applying PSM with difference-in-differences (Rosenbaum, 2012; Dehejia & Wahba, 2002). The main advantage of the adopted empirical strategy is that it does not rely on the correct specification of the relationship between the outcome and the covariates (as the propensity score is modeled without the outcome variables). On the other hand, the estimate is subject to selection bias, requiring the use of techniques to control for the intrinsic differences between the two groups, such as the PSM and difference-in-differences applied herein (IFS, 2015).

4.1 Data and sample design

Three databases with information disaggregated at the firm level were merged to generate the dataset used in this empirical study. The main source was the confidential database of PINTEC, a comprehensive survey on innovation conducted by the Brazilian Institute of Geography and Statistics (IBGE) every three years. To identify which firms benefited from the tax incentives, the PINTEC database was merged with the list of beneficiary firms publicly disclosed by the Brazilian Ministry of Science Technology and Innovation (2016) in its yearly reports on the Fiscal Incentives Law. The third data source was the public list of exporting and importing companies in the country each year released by the Brazilian Ministry of Economics (2017), which is used in this analysis to control for international trade activities.

Data from these sources were merged and organized in an unbalanced panel with information on 13,706 firms for 2008 and 2011, which were the two latest editions of this survey available when estimates were calculated [1]. Only firms present in both editions of PINTEC were considered so that the difference-in-differences framework could be adopted. All firms that benefited from the tax incentives before 2008 were excluded from the dataset to ensure that the trend was not biased at the outset. Additionally, to reduce the heterogeneity of the sample and improve the estimate of impact, the innovation input analysis was based exclusively on firms that reported positive spending in innovative activities ($N = 6{,}168$ firms).

The 303 firms in the sample listed as beneficiaries of the policy by the Brazilian Ministry of Science Technology and Innovation (2016) were considered the treated group (i.e. those that obtained the tax incentives), whereas the others constituted the control group. Firms in the control group that received incentives at any point in time were excluded from the analysis to ensure that secondary effects did not disturb the results.

The sample was further reduced because of missing data. In a number of cases, there was not complete information for the variables necessary for the analysis for unspecified reasons. This study adopted a "complete case analysis" to address the problem of missing data (Hughes, Heron, Sterne, & Tilling, 2019), which means that the investigation is limited to firms for which full information was available. The implications of this choice for the strength of the evidence and generalization of findings are discussed below.

4.2 Variables and descriptive statistics

Policy impact was assessed for two sets of outcome variables. The investigation first focused on innovation inputs and investment, measured through three indicators. The first was R&D spending, the most common outcome considered by the literature on innovation policy assessment (Hall, 2020). However, R&D is "only one component of innovative activity," representing less than half of the total innovation investment of innovative firms in the country (IBGE, 2020). Additionally, the Fiscal Incentives Law provides incentives for other innovative activities, as discussed in Section 3. Because of these limitations, the impact was also assessed for overall spending on innovative activities (OECD & Eurostat, 2018), which includes internal and external R&D; acquisition of knowledge from third parties; software license or acquisition; machinery and equipment; training; introduction of innovations in the market; and industrial design and other measures for production and distribution (IBGE, 2013). Finally, focusing on spending may not be sufficient to evaluate innovation policy, as additional expenditures on R&D or innovative activities may simply reflect changes in prices or higher salaries (Guceri, 2018). For this reason, the policy impact on the R&D headcount was estimated as a proxy of the change in the scale of innovation activities (Guceri, 2018).

The existence of positive impacts on innovation inputs does not necessarily mean that beneficiaries will yield better results in terms of innovation output and performance because of crowding-out effects and relabeling. For this reason, such dimensions were also investigated. The first indicator considered for this purpose was the share of sales generated by new products, which is a common measure of innovation output (Ognyanova, 2017). To investigate any potential effects on international activities (Freel *et al.*, 2019), the share of exports from new products was also assessed. Finally, the performance of beneficiary firms was considered in terms of total employment, net revenue and net revenue per employee (as a measure of labor productivity, following Nilsen *et al.*, 2020).

Participation in the policy was measured through a binary dummy variable that indicates whether each firm in the dataset belongs to the treatment or control group, i.e. whether they benefited from the tax incentives in the relevant year or not, using the list of beneficiaries published by the Brazilian Ministry of Science Technology and Innovation (2016). It was assumed that the incentives impacted innovation investment and input in the same year of treatment, i.e. 2011 (the latest observation period in the dataset). For the output and performance variables, there must be a time lag for projects and investments fostered or funded by the incentives to mature so that their results can be assessed. Thus, the three-year interval between each edition of PINTEC (IBGE, 2010, 2013) was used herein as the maturation period, following the recommendation of the Oslo Manual (OECD & Eurostat, 2018) for assessing innovation output. Therefore, for innovation output and firms' performance variables, the treatment was observed in 2008, and the results were observed in 2011.

Table 1 presents the direct comparison of means for treated and control groups without any prior matching. Nominal values for 2008 were adjusted for inflation using the IGP-DI

Outcome variables	Unit of observation[a]	Groups	N	Mean	Std. Dv.
Innovation input					
Innovative activities expenditures[b]	R$ 1,000	Control	2,540	2865.72	70514.74
		Treatment	220	−1260.73	38929.78
R&D expenditures	R$ 1,000	Control	1,135	2136.02	36877.84
		Treatment	189	3862.40	23897.93
Total number of R&D personnel	Number of researchers	Control	1,135	12.87	159.35
		Treatment	189	15.83	40.24
Innovation output and firm performance					
Percentage of sales from new products	Percentage of total sales	Control	2,235	−10.143	2.175
		Treatment	133	3.233	0.270
Percentage of exports from new products	Percentage of exports	Control	2,235	−2.622	0.393
		Treatment	133	−0.2093	0.031
Net revenue	R$1,000	Control	6,406	8226.55	213812.8
		Treatment	155	27650.29	715835.8
Total employment	Number of employees	Control	6,412	36.77	489.75
		Treatment	155	268.75	1164.98
Net revenue per employee	R$1,000	Control	6,271	−3.46	322.55
		Treatment	154	−112.07	408.52

Note(s): [a] Mean difference between real values in 2011 and 2008. Nominal values for 2008 were adjusted for inflation using the IGP-DI index (Central Bank of Brazil, 2021)
[b] According to the definition of IBGE (2013). Part-time researchers are weighted according to the work time dedicated to firm's R&D
Source(s): Prepared by the authors, based on IBGE (2010, 2013), confidential microdata

Table 1. List of outcome variables and descriptive statistics

index. Following the difference-in-differences approach, the table values indicate the difference between real values in 2011 and 2008.

The following set of covariates (X_i) were assumed to affect the odds of a firm obtaining the incentives, and they were therefore used in the treatment probability model used to estimate the propensity score: (1) firm size (number of employees–log-linearized); (2) net revenue (log-linearized); (3) firm age; (4) dummy for national controlling capital; (5) dummy for foreign controlling capital; (6) dummy for continuous R&D activity in the last three years; (7) dummy for firms belonging to a corporate group; (8) dummy for importing firms in the previous year; (9) dummy for exporting firms in the previous year; (10) dummy for firms that mainly sell to the international market; (11) dummies for each of the five country regions (North, Northeast, Middlewest, Southeast and South), excluding the state of São Paulo to avoid collinearity and (12) industrial sector dummies (ISIC, 2-digit level). Descriptive statistics for these variables are displayed in Table A1 of the Supplementary material.

4.3 Identification strategy

The parameter used to estimate the causal effect of the tax incentives was the average treatment effect on the treated–ATT (Rosenbaum, 2012). In a group of firms indexed by "i" containing a treated ($T_i = 1$) and a control group ($T_i = 0$), "Y_{i1}" is the value of an outcome for firm i if it is exposed to treatment (i.e. it obtains the incentives), while "Y_{i0}" is the value of the outcome if the same firm does not obtain the incentives. In this setting, the ATT measures the difference between the expected value of the outcome achieved by beneficiary (treated) firms ($E(Y_{i1}|\ T_i = 1)$) and the expected value of the outcome they would have achieved had they not obtained the incentives ($E(Y_{i0}|\ T_i = 1)$).

However, the latter value cannot be observed for treated firms, so it was necessary to estimate it using the control group. However, due to the selection bias problem, the expected value of the outcome for the control group ($Y_{i0}|\ T_i = 0$) does not provide a consistent estimate for the treated group, as firms in both groups are likely to be different.

The PSM was applied to control for these differences. The main assumption of the model is that the probability that a firm obtains the incentives is a function of a set of independent observable variables that can be merged in a single propensity score, i.e. the "conditional independence" or "selection on observables" assumption (Dehejia & Wahba, 2002).

If this assumption holds, once the propensity score is controlled for, firms in both groups would have had the same probability of obtaining the incentives, so participation in the policy can be deemed random. In this case, "Y_{i0}" becomes independent of treatment (conditional upon the propensity score), which means that its expected conditional value is the same for both groups, as presented in Equation (1). The selected control group can then be used as a suitable counterfactual to estimate the expected value of the outcome without incentives for treated firms.

$$Y_{i0} \coprod T_i | p(X_i) \Rightarrow E(Y_{i0}|p(X_i),\ T_i = 0) = E(Y_{i0}|p(X_i),\ T_i = 1) \tag{1}$$

In this analysis, the propensity score ($p(X_i)$) was modeled and estimated using the set of observable covariates X_i mentioned in the previous subsection and applying a logistic regression. Due to the missing data problem, a specific propensity score was estimated for each outcome variable, so it more appropriately reflects the probability of treatment for the firms used in each analysis. After excluding firms out of the common support, i.e. those with a propensity score above or below the level common to both groups, treated observations were matched with their first nearest neighbor in the control group. For each case, the quality of matching was assessed through a means test, ensuring that covariates were balanced between the two compared groups.

As the "selection on observables" assumption cannot be verified, the estimation of the ATT was improved using a difference-in-differences framework. For such analysis, the absolute value of the outcome variable is replaced by the difference between the values after (Y_{iT}^1) and before (Y_{iT}^0) the treatment effect took place. This method weakens the assumption by controlling for any time-invariant nonobservable factors (Blundell & Costa Dias, 2000). Considering the lag between the editions of PINTEC used for this analysis, the baseline values were observed in 2008, while the posttreatment outcomes were observed in 2011.

Following the above procedures, the ATT was estimated herein as presented in Equation (2), i.e. the expected difference in average outcome in the treated group before and after treatment conditional upon the propensity score *minus* the expected difference in average outcome in the control group before and after treatment also conditional upon the propensity score.

$$\text{ATT} = E\left(Y_{i1}^1 - Y_{i1}^0|p(X_i)p(X_i),\ T_i = 1\right) - E\left(Y_{i0}^1 - Y_{i0}^0|p(X_i),\ T_i = 0\right) \tag{2}$$

To assess the sensitivity of the results to bias caused by nonobservable variables, the "Rosenbaum bounds" procedure (Rosenbaum, 2012) was applied to the outcome variables with statistically significant ATTs. The Rosenbaum bounds test determines the maximum value that the ratio of odds of treatment for treated and control units can take due to potential unobserved variables without compromising the statistical significance of the results. It was calculated through the Wilcoxon sign rank test (upper and lower bounds for p-values) and the Hodges-Lehman point estimates and confidence intervals, using intervals of (0.1) up to the value of two.

5. Results and discussion

The estimated logit propensity scores are presented in Table A2 of the Supplementary material, and the effect of each covariate on the probability of treatment is displayed. Net revenue is the single most important continuous covariate, with a positive and significant coefficient at the 99% confidence level for all cases, meaning that companies with higher income are more likely to benefit from the incentives. The continuous development of R&D activities also increases the probability of obtaining tax incentives in nearly all models. The results of the means tests for covariates and for the propensity score are presented in Tables A3 to A10 of the Supplementary material. For all models, few variables present significant differences after matching, with a substantial reduction in the standardized bias for the majority of the cases, mitigating possible bias selection. In all cases, the log-likelihood test ($p > \chi^2$) does not reject the joint insignificance hypothesis for matched samples, and the pseudo-R^2, mean and median bias also drop considerably. These results provide good grounds to accept the propensity score specification.

The estimated ATTs are displayed in Table 2. The results for input outcome variables indicate that the policy increased the R&D expenditures of treated firms by approximately 500,000 Brazilian *reais* (US$ 264,000, according to the exchange rate applicable on the last day of 2011) on average. This effect represents 6.8% of the mean R&D spending of beneficiary firms in 2011 (approximately 7.3 m Brazilian *reais*, according to the microdata in IBGE, 2013) and a 76% relative effect compared to the growth observed in (matched) control units. Also, an average positive impact of approximately five researchers on R&D personnel was found. This outcome represents 16% increase over the average number of R&D staff of beneficiary firms in 2011 (the mean number of researchers per treated firm in 2011 was 30.39, according to the microdata in IBGE, 2013) and a 51% relative effect.

These findings are in line with previous empirical studies for Brazil and other countries that also found a positive and statistically significant impact of tax incentives on R&D spending (Avellar, 2008; Tian *et al.*, 2020; Rao, 2016) and on research personnel (Kannebley *et al.*, 2013; Guceri, 2018). The results can be construed as empirical evidence of the input additionality of the policy, suggesting that government intervention and a reduction in tax

Set	Outcome variables	Mean value per group Treated	Control	Difference	Relative effect (diff/control)
Innovation input	Innovative activities expenditures (R$ 1,000)	497.75	969.86	−472.11 (373.26)	−0.49
	R&D expenditures (R$ 1,000)	1151.19	655.47	495.72*** (169.63)	0.76
	Total number of R&D personnel	14.39	9.54	4.85** (2.22)	0.52
Innovation output and firm performance	Percentage of sales from new products	3.79	−3.97	7.75 (5.73)	−1.96
	Percentage of exports from new products	0.02	−1.45	1.47 (5.05)	−1.01
	Net revenue (R$ 1,000)	11207.67	3016.92	8190.75 (16978.93)	2.72
	Total employment	140.67	33.19	107.48*** (37.34)	3.24
	Net revenue per employee (R$ 1,000)	−111.27	−13.60	−97.67 (66.95)	7.18

Note(s): All variables represent the difference between real values in 2011 and 2008. Standard errors in parenthesis. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$. Matching algorithm: nearest neighbor. Standard error estimated according to Abadie and Imbens (2006)
Source(s): Prepared by the authors, based on IBGE (2010, 2013), confidential microdata

Table 2. Estimated average treatment effect on the treated (ATT)

costs succeeded in increasing total business R&D investment, partially mitigating the negative effects of market failures in such investment.

On the other hand, no significant evidence of the impact of the incentives on overall spending in innovative activities was found. This result suggests that although firms benefiting from tax incentives did more R&D, they did not spend more where total innovation investments were concerned. The explanation for the conflicting results for R&D and total innovation investments requires further investigation, but the reviewed literature provides potential hypotheses for discussion. First, firms may have simply relabeled related expenses as R&D to claim them under the incentive (Chen *et al.*, 2018). Second, the absence of an impact on innovative activities expenditures may simply reflect a crowding-out effect that may negatively affected the gains of the policy (Zúñiga-Vicente *et al.*, 2014).

No evidence of impact was found for the percentage of sales or exports generated by new products, net revenue and net revenue per employee. The only positive and statistically significant effect was found for total employment, which was estimated to be approximately 5% of the mean size of treated units in 2011 and a similar result to that reported by Kannebley *et al.* (2013). Although these findings are troubling from an innovation policy perspective, they also reflect the difficulties of assessing the output additionality of innovation policies (Hill, 2013; Gault, 2013), thereby suggesting the need for further research on the topic.

The results of the Rosenbaum bounds sensitivity analysis are displayed in Table A11 of the Supplementary material. In the case of R&D expenditures and firm size, the cutoff point is found within the interval ($1.2 < \Gamma < 1.3$) for the Hodges-Lehmann estimates and ($1.3 < \Gamma < 1.4$) for the Wilcoxon signed-rank test. This means that the odds ratio between the treatment and control groups must rise at least 20% above unity to render the ATT statistically nonsignificant. In light of the comprehensiveness of covariates used in the study, the result can be considered moderately insensitive to hidden bias. In the case of R&D personnel, the test indicates significance is lost at low (Γ) values, meaning this estimate may be very sensitive to influence from unobserved variables.

The results presented herein provide relevant insights for discussing the policy and proposing improvements to its design. The first point is the importance of adopting a broad concept of innovative activities not limited to R&D (Hall, 2020) to reward firms for other innovative investments and to thus increase productivity and competitiveness. The results also suggest a substantial crowding-out effect that needs to be addressed so that the incentives act to increase private investment in innovative activities. This is a difficult problem to address, and it is found in innovation policies worldwide (Zúñiga-Vicente *et al.*, 2014). In addition, increasing the sales and exports of new goods and labor productivity are also some of the main challenges of the policy. Devising a strategy to meet these targets requires qualitative research, including case studies and surveys, with beneficiary companies to better understand why the increase in R&D and research personnel was not followed by better results in these output indicators.

This study was based on a rich dataset with information on Brazilian firms from different sources and on an empirical strategy used in the most recent literature on the impact assessment of innovation policies (Lane, 2020). However, the analysis has limitations that need to be considered when interpreting the results, which may be the subject of future research. First, it is based on the available data in the original databases at the time they were accessed and disregards observations with missing data (Hughes *et al.*, 2019). Although the sample is meant to be representative of innovative firms in the country, this cannot be verified; therefore, the generalization of the findings should be made with caution. In addition, innovation output and firm performance are only considered within a three-year timeframe (as recommended by OECD & Eurostat, 2018); thus, any impact of the policy after this period is not accounted for in this analysis. Finally, the model specification does not consider other innovation incentives and subsidies that were in place during the studied period, suggesting the possibility of a "multiple treatments" problem (IFS, 2015).

6. Concluding remarks

The Fiscal Incentives Law represents an inflection point in the use of fiscal measures to foster business innovation in Brazil in terms of tax generosity, investment volume and number of beneficiary firms. This paper presents an assessment of the impacts of the tax incentives provided by the law on beneficiary firms' innovation input and output and on their performance. It contributes to the existing studies on the Brazilian innovation tax policy by assessing its effects on the bulk of innovative activities (in addition to strict R&D investment) and on indicators of innovation output and firm performance. In addition, this study is part of a broader and recent empirical literature dedicated to investigating the output additionality of innovation policies, discussing how they affect the results of business innovation efforts.

The results suggest a causal impact of the policy on R&D expenditures (average of approximately US$ 264,000 in 2011), the number of research staff (average of five researchers) and the growth of beneficiary firms (approximately 5% of the beneficiary firms' mean size). These findings provide empirical support in favor of tax incentives as a relevant part of the government strategy to boost business innovation in the country. On the other hand, no evidence of impact of the incentives is found for innovative activities expenditures, the share of sales and exports from new products, net revenue and firms' productivity. These are an important result because they reveal shortcomings of the policy that need to be addressed to improve its results.

The analysis suggests future research questions relevant to improving our understanding of the Fiscal Incentives Law and its role within Brazilian innovation policy. The policy additionality regarding innovation output and firm performance deserves further investigation, both because of the difficulties in assessing such dimensions and because this seems to be an important challenge of the policy according to the results presented herein. Second, future studies using more updated and complete data may be able to overcome the limitations of the sample discussed previously and to control for other forms of government support when estimating the effects of tax incentives. Finally, the role of innovation tax incentives in the context of a reduction of government support for innovation (as the country has since 2014) is another point that needs further research for better understanding and improvement of the Fiscal Incentives Law.

Note

1. Access to PINTEC confidential firm-level data was granted by IBGE for purposes of this research. The data were accessed at IBGE's confidentiality room in July, 2016.

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Supplementary material
Supplementary material is available online for this article.

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