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ARTIGO

Does public procurement for innovation increase innovative efforts? The case of Brazil

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ABSTRACT

The paper uses microdata from the Brazilian Innovation Survey to assess the effect of public procurement on firms' private R&D expenditures. The PINTEC 2014 edition included in its policy module a new question about public procurement related to firms' innovative activities. The paper uses this information to define a treated sample composed by firms that participated in public procurement with innovative attributes. The paper builds a control sample through coarsened exact matching and tests the effect of innovation-related public procurement on firms' private R&D to sales ratio. The results suggest a positive impact of public procurement of innovation on R&D intensity. Data also shows that most firms involved in PPI are small and belong to low-technology sectors. These features disclose an important characteristic of the public procurement of innovation: its ability to target small firms and contribute to local development.

KEYWORDS | Public Procurement of Innovation; Policy Assessment; Demand-Side Innovation Policy; Brazil

JEL: O25; O38: L50

Compras governamentais para inovação aumentam o esforço inovador? Evidências ao caso Brasileiro

Resumo

Este artigo usa microdados da Pintec para aferir o efeito da política de compras governamentais para inovação no Brasil sobre os gastos em P&D. A Pintec 2014 inclui uma nova pergunta sobre o uso pela empresa das compras governamentais para inovar. O artigo define que empresas que responderam "sim" a essa pergunta participaram de programas de compras para a inovação. A seguir, é construída uma amostra de controle usando uma técnica de pareamento exato por estratos e testado o efeito dessas ações sobre a razão entre gastos privados em P&D e vendas (intensidade de P&D). Os resultados sugerem um efeito positivo da política de compras para a inovação sobre a intensidade de P&D. Ele é particularmente importante quando se percebe que as empresas envolvidas nesse tipo de instrumento de política são menores e atuam em setores de menor intensidade tecnológica quando comparadas com as empresas que usam outros instrumentos de inovação, sugerindo um papel especial do instrumento na política de inovação. O artigo então sugere um importante atributo da política de compras: alcançar pequenas empresas e contribuir para o desenvolvimento local.

Palavras-chave: Política de Compras para a Inovação; Avaliação de Política; Políticas de Inovação de Demanda; Brasil

JEL: O25; O38: L50

1. Introduction

The shift of interest of policymakers and scholars towards demand-side innovation forces has put public procurement for innovation (PPI) in the center of the debates on innovation policy. This new wave of studies has been illuminated by the systems of innovation approach. According to this view, innovation requires the use of complementary assets and knowledge held or controlled by different agents. Innovation is seen as an interactive process and policy should be able to, foremost, handle this complexity and provide complementary institutions whenever knowledge should be trapped in lock-in situations (STEINMUELLER, 2010). The emphasis of the literature relies on the need for policy measures and instruments that promote the interaction between agents. Demand is an important part of the innovative environment and procurement is an especially significant instrument (EDQUIST; VONORTAS; ZABALA-ITARRIAGAGOITA, 2015; UYARRA, 2012; EDLER; GEORGHIOU, 2007; UYARRA; FLANAGAN, 2010; BLOCK, 2008; MAZZUCATTO, 2011). Of course, the traditional view on the role of public procurement in reducing the risks involved in innovative activities is also an important argument, as authors have long emphasized the role played by government procurement in fostering innovative efforts (LITCHENBERG, 1987, 1988; GEROSKI 1990).

The literature has struggled over an adequate definition of PPI. The most diffused one stresses the presence of demand for products that do not exist in the market (EDQUIST; HOMMEN; TSIPOURI, 2000), opposing off-the-shelf procurement. However, in between these two extremes, there is a wide range of practices that may be useful to policymakers in the building of innovative environments and innovation networks. This paper will focus on the notion of adaptive-technology PPIs that can make room for the improvement of local firms (EDQUIST; HOMMEN, 2000; EDQUIST; ZABALA-ITURRIAGAGOITIA, 2012; UYARRA; FLANAGAN, 2010, 2011). Among these practices, driving public procurement away from single lowest-price targeting is an important measure (UYARRA, 2012).

Historically, public procurement in Brazil has suffered from this limitation and privileged price targets over quality and innovative attributes. Not surprisingly, previous studies on the conduct and performance of public sector suppliers have found that firms that supply to the public sector display lower capabilities and performance when compared to other type of firms (SOARES, 2005; SQUEFF, 2014). In 2010, however, government passed a new legislation that permitted public

sector procurement to pursue other goals rather than the lowest prices and allowed the practice of a preference margin of up to 25% to promote the development of technology through procurement. This was a big step towards a different agenda for public sector procurement. Previous experiences on PPI in Brazil, though restricted to strategic sectors, showed positive results (RIBEIRO, 2017; RAUEN, 2017; ROCHA, 2017). However, no general tests analyzing the role played by procurement from the public sector as a whole on firms' innovative activities.

This paper aims at assessing the effect of the use of PPI as an innovation policy instrument on private R&D expenditures of firms in the Brazilian Mining and Manufacturing industries. To achieve this task, the paper uses microdata from the Brazilian Innovation Survey (PINTEC). PINTEC inaugurated in its 2014 edition a question that asks firms whether they used a public procurement program to carry out innovative activities. Thus, we are testing whether firms that have used public procurement to innovate have enhanced their innovative efforts.

This paper is organized in five sections, including this introduction. The second section describes our analytical background, the definition and understanding of PPI used here and the main empirical results of previous literature in the Brazilian case. The third section is dedicated to a description of the database, the firm population involved, and the assessment methods used. Section four presents the results of the regressions and discusses them in the context of the PPI literature. Section five draws and presents the main conclusions from the evidences and discussions.

2. Analytical background

There are two different approaches towards innovation policy depending on the vision one holds about the innovation process. The first view is more directly based on a linear conception of innovation policy and stresses the characteristics of knowledge (as a good) and its main market imperfections. This view pays attention to externalities, which may bestow public-good characteristics to innovative activities, and to asymmetric information and uncertainty that may determine underallocation of financial resources. Both characteristics deviate the allocation of resources from Pareto optimality. In these cases, market intervention may be a way to conduct the allocation back to Pareto optimality or to second-best situations. Property rights legislation and the correction of market prices are some of the prescribed policies. Resources may also be channeled through the financing of R&D activities, the building of financial mechanisms and institutions such as

venture capital funds, fiscal incentives, and the supply of non-reimbursable funds (HALL, 2010; ARROW, 1962).

In turn, the network view emphasizes the systemic character of innovative activities and stresses the importance of structuring innovation networks. Innovation is not an isolated phenomenon and it requires capabilities that may be accumulated by more than one actor (FAGERBERG, 2005; EDQUIST 2005). Thus, innovation requires the involvement of firms that hold complementary capabilities and the combination of these firms may face challenges that inhibit innovative efforts. Innovation policy should be used to overcome these obstacles by assigning new missions for public institutions, whenever one identifies systemic dysfunctions, creating new intermediary and complementary institutions to foster interaction and cooperation, and supporting industrial initiatives involving the creation of new technologies (STEINMUELLER, 2010).

Thus, there are important analytical consequences in the adoption of a network view of innovation: one should deal with the complexity of the innovative process, as supply-side characteristics are only a part of the problem (EDLER; GEORGHIOU, 2007); the way actors of innovation networks interact matters, and this may differ across nations (LUNDVALL, 1992; NELSON, 1993), regions (CASSIOLATO; LASTRES; MACIEL, 2003), and sectors (MALERBA; NELSON, 2011); the institutional framework and infrastructure where the innovation system or network is embedded should affect innovative behavior; and the enhancement of innovative activity may involve the improvement of ongoing linkages or the establishment of not-yet-existent ones. Policy should therefore primarily enable "learning-oriented interactions" and should be capable of fostering linkages between actors of the system or network (EDQUIST; VONORTAS; ZUBALA-ITURRIAGAGOITIA, 2015, EDLER; GEORGHIOU, 2007).

Public procurement may more specifically answer the challenge of building intermediary and complementary institutions to foster interaction. This requirement arises because markets frequently involve information asymmetries and it may be necessary to have complementary institutions to deal with them, and, most importantly, to find new opportunities, coordinate actors of the system and provide the necessary exchange of knowledge to promote innovation. PPI may shape demand addressing the need to find new opportunities and to provide guidance towards the future, which may provide the necessary risk reduction to enable innovative investments and coordinate efforts across firms, often defining ways to exchange information.

In the most well-known definition, PPI "occurs when a public agency places an order for a product or system which does not exist at the time, but which could (probably) be developed within a reasonable period" (EDQUIST; HOMMEN; TSIPOURI, 2000, p. 5). It is a consensus that this definition may be too strict to cover all possible modes of PPI. Even Edquist, Hommen, and Tsipouri (2000) describe some public procurement goals that do not fit into this straightforward definition but may improve business activities. The presence of these types of functions may widen the range of roles PPI may play. Public procurement for innovation may involve activities that have innovative attributes but are not related to an inexistent product or service. PPI may include the improvement of existing products or the capacitation of firms to produce previously imported products domestically (locally). PPI should have innovative attributes to "target functions that satisfy human needs or solve societal problems" (EDQUIST; ZABALA-ITURRIAGAGOITIA, 2012). These attributes may imply local innovative behavior, although it may involve no novelty globally and, thus, be more strongly related to what Edquist, Hommen and Tsipouri call adaptive PPI. The latter is mostly related to the diffusion of new procedures, while it may also include developmental PPI, which is the common-sense perception of PPI and related to the development of new technologies. In this event, and mostly for the Brazilian case, it is more likely that adaptive PPI should be a major goal of governments.

Under these arguments, the definition of PPI must include: those initiatives directly related to bringing about solutions not present in the market context before they take place; the use of innovation-friendly practices that may promote new practices to public providers of goods and services; and the establishment of conditions conducive to firm capacitation and interactive learning, allowing for the use of adaptive PPI.

There are advantages in using PPI. First, it provides a more interactive environment, in that there is exchange of information in the specification of products and needs or even in the joint development of these products (MAZZUCATTO, 2011; BLOCK, 2008). PPI may be a source of information on the demand for sophisticated goods (EDLER; GIORGHIOU, 2007). Second, it may be a source of reduction of uncertainty. Governments may provide an important market and scale for newly developed products (LITCHENBERG, 1987). Governments may also be a guarantee of demand in the case of new products that are still inexistent in the market. PPI may provide the correct environment and reduce market uncertainty (BLOCK, 2008). In the case of high uncertainty, the procurement of pre-commercial

R&D may be a way to overcome technological uncertainty that arises from the market, as was done in the ARPA project in the US (BLOCK, 2008).

PPI may be an explicit or an implicit instrument of innovation policies (UYARRA; FLANAGAN, 2010). Rothwell (1984) advocates a more explicit role of PPI, mostly directed to the development of local capabilities. His main point is that regional development policies have been largely unsuccessful due to their incapacity to develop local capabilities. Thus, Rothwell (1984) proposes the use of PPI, together with other innovation policy instruments, to develop innovative behavior in local small firms. His arguments rely largely on the experience of the US National Bureau of Standards, which promoted a change in public procurement away from the purchasing of the "cheapest products that met minimal design standards" towards the specification of "performance needs rather than design standards and purchased products with the lowest life cycle costs" (HERBERT; HOAR, 1982 *apud* ROTHWELL, 1984, p. 323).

PPI may direct the governmental purchasing power towards innovation, by: creating an environment that is responsive to innovation; stimulating the diffusion of new techniques and products; being proactive in the creation of new products and processes; specifying new needs; or even procuring R&D itself, in the case of pre-commercial R&D (EDLER *et al.*, 2013).

Some of these uses of PPI are particularly important in developing countries where there is high structural heterogeneity due to the uneven diffusion of technical progress across and inside sectors (PINTO, 1970). The presence of a qualified client that requires up-to-date, quality products, demands innovation from suppliers and interacts with them aiming the capacitation of firms may be an important tool to overcome some of the obstacles to the diffusion of technical progress, mostly when it comes to small firms. This concern coincides with Rothwell's approach to PPI towards the capacitation of small firms in the regional development.

However, PPI may face important obstacles for its implementation. Public sector agencies, companies and agents may lack the necessary capabilities as a client to specify or jointly develop products. Risk averse public agents may also jeopardize the full potential of public procurement and public legislation may be disproportionately focused on price as the key variable (UYARRA, 2012).

Brazil's governmental procurement, since the promulgation of Law n. 8,666/1993, was mostly directed towards the acquisition of the "cheapest products that met minimal design standards". The country's first general step towards the strategic use of procurement for innovative policy purposes appeared in the Innovation

Law, promulgated in 2004 (10973/2004). The latter authorized governmental entities to procure R&D services and to promote the development of technology through procurement (RAUEN, 2015). The first time PPI explicitly appeared as a governmental strategy was in the Policy for Productive Development launched in 2008. However, only in 2010 did the government pass a bill that changed the rules for federal procurement and made viable the hiring possibilities that had been proposed in the Innovation Law, allowing the use of a preference margin of up to 25% for domestic firms over foreign suppliers' price (Law n. 12,349/2010) and, most importantly, ending a long period that had focused on price rather than quality and innovative attributes (SOUZA; OLIVEIRA, 2010).[1]

Law n. 12,349/2010 was followed by the edition of Federal Decree n. 7,546/2011, which established the conditions under which it could be used. This new legislation accepted the use of the preference margin to induce the improvement of suppliers' practices and products and the operation of procurement policy for innovative purposes. The legislation allowed restrictions of local content in the acquisition of communication and informatics equipment; it also permitted a waiver from the use of public auctions for the acquisition of equipment, whenever the use of resources originated in agencies for the support of public innovation, and the use of alternative methods of procurement, whenever the exchange of knowledge across economic agents was involved. In the following years, a sequence of public decrees developed specific contract designs using this legislation to attend to different economic sectors (SQUEFF, 2014).

It is therefore no surprise that previous empirical works that have analyzed the effect of public procurement on innovation have not shown good results. Soares (2005) analyzes the characteristics of firms that supplied to the Brazilian government from 2001 to 2003. He shows that the higher the share of governmental acquisitions in firms' sales, the lower their innovative behavior and efficiency according to various indicators. Squeff (2014) reproduces Soares' (2005) method with a larger time horizon, 2000 to 2010. She also finds a negative correlation between the share of governmental acquisitions in firms' sales and indicators related to innovative behavior. The main conclusion from their work is that the most plausible effect of government procurement is to depress innovative capabilities. This result does not generally agree with international evidence (EDQUIST; VONORTAS; ZABALA-ITURRIAGAGOITIA, 2015), though evidence for developing countries displays

1 Before this, there had been few initiatives at the sectoral level, mostly related to local content policy, as was the case of oil and gas (ROCHA, 2017).

mixed results, mostly due to lack of policy capacity (KATTEL; LEMBER, 2010). Nonetheless, in the case of Squeff (2014) and Soares (2005), they do not analyze PPI, but off-the-shelf procurement for their research was carried out when preference margins were prohibited, and quality discrimination was avoided by legislation.

Analyses covering explicit PPI experiences before Law n. 12,349 draw a more positive picture. The procurement practices of Petrobras[2] appear to have a positive effect on the innovative behavior of its critical equipment suppliers, showing a positive effect on the hiring of technical and scientific personnel. Furthermore, there was a tendency in this case for a larger effect on small firms, accompanying some of Rothwell's (1984) conclusions (ROCHA, 2017). The development of EMBRAER, a state-owned company until 1994, and a major commercial aircraft builder, is another of these experiences. Orders from the Brazilian Department of Defense have helped EMBRAER to build new competences in the area, before and after the company's privatization. The development of the AMX jet fighter was central for the development of the ERJ 145 and EMBRAER 170/190 families. Today, the Brazilian Air Force is developing, alongside EMBRAER, the KC 390 that will substitute the Hercules carriers in military operations (RIBEIRO, 2017). The Sirius project, which has built a new particle accelerator in Brazil, has also shown a positive experience in developing suppliers' competences. This project involved the hiring of pre-commercial R&D through subvention and subsequent use of the results to obtain national solutions for the supply of equipment (RAUEN, 2017).

Nonetheless, despite the approval of new legislation, there is a general feeling amongst analysts that adequate policy is still to be formulated. The new law has not been accompanied by an effort to provide guidelines about in which situations PPI should be used and what strategy should be followed. Furthermore, there is doubt whether the staff that are responsible for federal procurement have the abilities and capabilities to perform this new task (MOURÃO; CANTU, 2014). The sole exception to this general challenge seems to be the program Inova Empresa, carried out by FINEP, mostly after 2013, which attempted to link supply side instruments with demand from public actors in strategic sectors.[3]

However, little is known about the effect of Law no. 12,349/2010 on the innovative behavior and performance of firms. Part of this limitation is due to the difficulties in separating what is PPI from what is not. This paper will attempt to cover this shortcoming using new information available on the 2014 edition of the

2 The Brazilian state-owned oil company.

3 In general, this program will be out of our time range.

Brazilian Innovation Survey. It questioned firms on the use of public procurement programs to the development and market introduction of firms' innovative products. The paper holds the hypothesis that PPI has played a very important role in incentivizing firms to innovate and that this is central due to the size distribution of governmental suppliers.

3. Methodology

3.1 The database

This paper uses data from the Brazilian Innovation Survey (PINTEC) for 2014. PINTEC is designed according to the principles of the Oslo Manual. The survey uses stratified sampling to produce statistically-significant samples of companies in the 10 to 29, 30 to 99, 100 to 249 and 250 to 499 employees strata and full coverage for companies with 500 or more employees. The survey also builds statistically-significant samples across two-digit sectors according to the International Standard Industrial Classification (ISIC4). It departs from the view that innovation is a rare event and thus attempts to cover all firms that have received or applied for governmental financial support and patents. Though the coverage of PINTEC also includes utilities and services firms, this paper will cover only firms in the manufacturing and mining industries. This decision is based on the need to obtain information on wages and number of employees from the Annual Industrial Survey (IBGE's Pesquisa Industrial Annual (PIA)) that only covers the manufacturing and mining industries. PINTEC 2014 interviewed a sample of 14 thousand manufacturing and mining companies, expandable to a total of 116 thousand firms of which 42 thousand were found to have introduced a new product or a new process to the firm from 2012 to 2014, and 17 thousand received public support for innovative efforts in the same period, most of which was directed to special financial conditions for the acquisition of machinery.

The 2014 PINTEC edition asked a question related to PPI for the first time. In previous PINTEC versions, PPI was supposed to be included in "other" instruments. This is thus the first time PINTEC offered the opportunity to check the role played by PPI. The question described in the questionnaire does not, however, mention the specific law into which the instrument should be framed (in this case, Law n. 12,349) as it does when dealing with fiscal mechanisms, for instance. This is one important shortcoming in the methodology, for it does not allow the discrimination

of the use of the law and leaves the definition of PPI solely to the perception of the firm's representative. It should also be stressed that, by not addressing Law n. 12,349 directly, the survey may only indirectly assess the potential of legislation changes. More specifically, we test the role that public procurement plays on firms' innovative efforts.

An additional methodological concern is about the time dimension. All of PINTEC qualitative questions refer to the 2012-2014 period, while the quantitative questions (on R&D expenditures, for instance) refer to 2014. This may create some biases in the analysis. First, the response time to treatment is still unknown and, therefore, we could be failing to capture the whole effect of the treatment on efforts. Second, the time frame is not homogeneous amongst treated firms. Some firms may have been treated in 2012 and others in 2014. Third, the effect of treatment may be perennial or temporary, and this again may influence results.

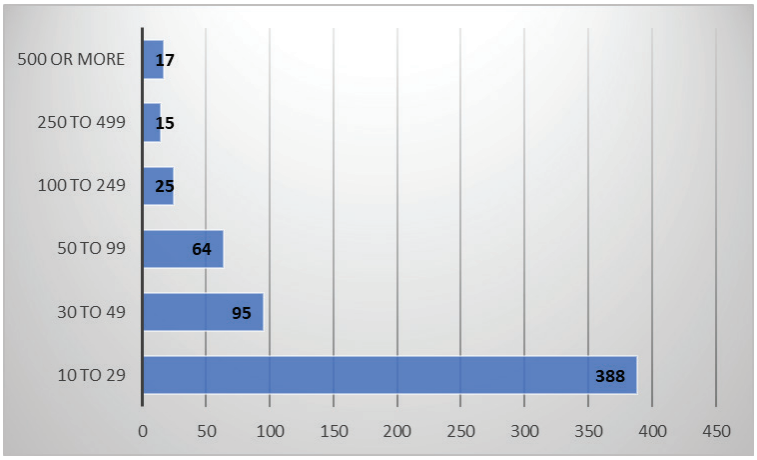
In the expanded sample, PINTEC finds that 604 manufacturing and mining firms had benefited from public procurement programs. This is a small part of the total purchases of goods and services by the Brazilian government. Squeff (2014) finds almost 20 thousand manufacturing firms participating in general governmental procurement, of which 2.4 thousand were listed in the Industrial Annual Survey (PIA). The large difference between the number of firms participating in general procurement and firms that responded "yes" to the question about PPI suggests that firms were able to distinguish between the two types of programs.

The distribution of firms in PPI per size is presented in Figure 1. PPI has the most favorable distribution towards small firms of all the policy instruments listed by PINTEC. Less than 10% of firms participating in PPI have 100 or more employees. The sectoral distribution of firms in the program is shown in Figure 2. The most frequent sector to use PPI is rubber and plastics, followed by food, wearing apparel and machinery. The sectoral distribution is important because it shows that most firms do not belong to high-technology sectors, although most of them have declared themselves as innovative.

The paper will not use expanded sample statistics and thus it will only rely on information provided by actual questionnaire respondents. As the sampling strategy of PINTEC guarantees full coverage for firms over 500 employees, the sample is biased towards larger firms. Furthermore, it was necessary to work with data for sales and wages and PINTEC does not collect them; rather, it uses information from the PIA. The Annual Industrial Survey (PIA) covers all manufacturing and mining firms with 30 or more employees and a representative sample of firms with between 5 and 29 employees, resulting in a total of 48 thousand Thus, firms between 10

and 29 employees selected in the PINTEC sample are not necessarily covered by the PIA. We have chosen to use only original information from the PIA and thus our sample has been reduced from 14 thousand to 10 thousand firms. The loss of coverage was almost totally located in firms between 5 and 29 employees.

FIGURE 1
Firms that participated in PPI, per size strata
Brazil – 2012-2014



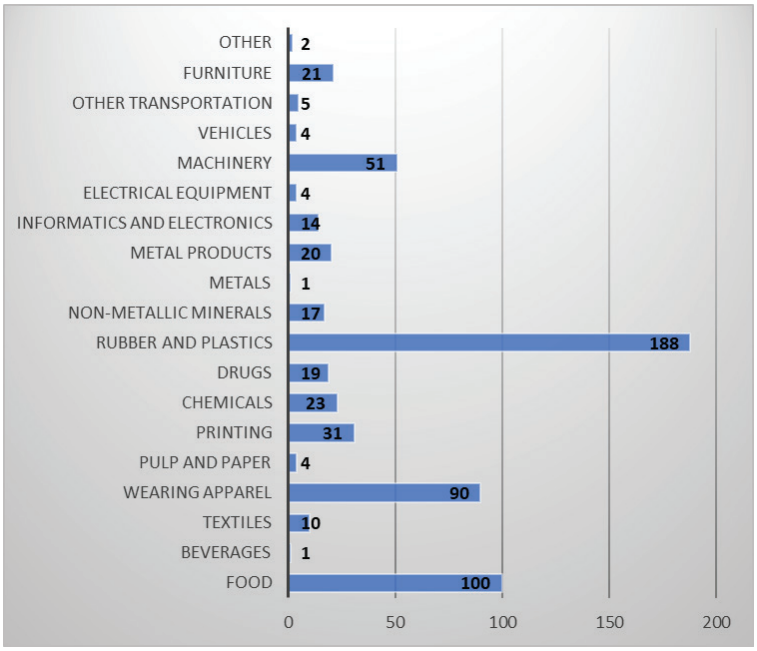
Source: IBGE, PINTEC (2014).

Table 1 shows PINTEC questionnaire respondents according to firm size and the receipt of treatment by PPI. In total, 69 respondents declared to have been part of PPI programs and 65 out of these 69 declared to have introduced either a process or product innovation. Firms that participated in PPI programs were, on average, larger in size and paid higher wages than other respondents (see Table 2). Table 2 also shows two statistics for in-house R&D intensity. The first is the ratio of the firms' entire R&D expenditures to sales. The second refers to net R&D expenditures with governmental support. PINTEC allows information on what percentage of a firm's R&D expenditure has been funded by their own resources and what percentage comes from the government or governmental agencies. The statistics in the last column of Table 2 refer only to the amounts that come from the firms' own funds.

One important characteristic of PPI-targeted firms is that they use other innovation policy instruments (Figure 3). A first consequence of this trait is that one should account for the effects of these instruments over firm conduct and performance (GUERZONI; RAITIERI, 2016). A second consequence is that these

firms may be characterized as more aggressive actors in the innovative setting, eager to participate in governmental policies.

FIGURE 2
Firms that participated in PPI, per sector
Brazil – 2012-2014



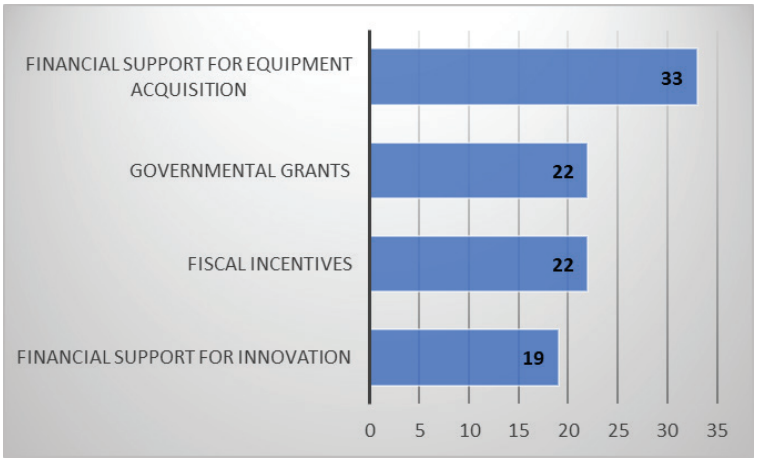
Source: IBGE, PINTEC (2014).

TABLE 1
Distribution of PINTEC questionnaire respondents by firm size strata, treated and non-treated with PPI – 2014

Firm size strata	Non-PPI	PPI	Total
10 to 29	283	3	286
30 to 99	3,522	27	3,549
100 to 249	2,835	16	2,851
250 to 499	1,636	8	1,644
500 to 999	903	4	907
1,000 or more	792	11	803
Total	**9,971**	**69**	**10,040**

Source: Own elaboration using microdata from PINTEC (2014).

FIGURE 3
Firms in PPI Programs that used other innovation policy instruments, per instrument – 2012-2014



Source: Own elaboration using microdata from PINTEC (2014).

TABLE 2
Descriptive statistics of non-PPI and PPI participants, questionnaire respondents – 2012-2014

Non-PPI and PPI participants		Number of employees	Number of innovative firms	Average wage	R&D/sales	Private R&D/sales
Non-PPI	Count	9,971	9,971	9,965	9,971	9,971
	Mean	452	0.527129	44	0.004633	0.004077
	SD	183	0.499289	36	0.023315	0.020995
PPI	Count	69	69	69	69	69
	Mean	516	0.942029	54	0.023257	0.020524
	SD	106	0.235401	51	0.053347	0.051928
Total	**Count**	**10,040**	**10,040**	**10,034**	**10,040**	**10,040**
	Mean	**452**	**0.52998**	**45**	**0.004761**	**0.00419**
	SD	**182**	**0.499125**	**36**	**0.023696**	**0.021398**

Source: Own elaboration using microdata from PINTEC (2014).

3.2 Selection biases

One of the main obstacles to policy assessment is the presence of selection biases. They have two origins. On the one hand, risk-averse government officials may choose the best firms to guarantee positive results for their intervention attempts;

thus, a positive correlation between behavior or performance and policy may be a consequence of choosing the better firms and not of having a good instrument. One the other hand, firms that already have innovative attributes may be more likely to present themselves to absorb the benefits of that policy. However, there may be no net result.

Most recent studies use a quasi-experimental method, trying to compose a control sample with similar initial characteristics to the treated sample through matching. The aim of matching exercises is to equate the distribution of chosen characteristics (covariates) of the treated and control samples. The ideal matching would find identical twins for each treated subject.

The use of matching requires the adequate design of the exercise, highlighting the main exogenous firm characteristics that may affect the outcome, as well as the analysis of the outcome only after dealing with the identified characteristics through the balancing of samples (STUART, 2010). The approach to the experiment design should involve an adequate analysis of firms' characteristics not affected by the treatment that may influence the outcome. The covariates should not be affected by the treatment and should include all firm's characteristics that may affect outcomes. This analysis has two important constraints: the available information on characteristics that may affect the outcome and the size of the population from which to draw the control sample. These constraints impose trade-offs and may influence the matching exercise one chooses.

Stuart (2010) lists four distance measures to build the matching exercise: exact matching; Mahalanobis; propensity score; and linear propensity score. If the objective is to find the exact twins of treated objects, exact matching should be the preferable method. However, there are two important limitations. The use of covariates that may have too many values reduces the number of observations, due to the high requirements to match the specific characteristic accurately. The same observation limitation occurs when including too many covariates. Both problems are very costly in terms of loss of observations and may face larger limitations when dealing with small samples. Most papers on innovation policy choose to use propensity score matching (PSM). King and Nielsen (2016) argue, however, that the use of PSM may, contrary to its main objective, increase imbalance and inefficiency, due to its attempts to approximate a completely randomized experiment, rather than blocking a randomized experiment. One way to overcome these limitations is the use of coarsened exact matching, which allows the use of categories instead of working with exact values (IACUS; KING; PORRO,

2012). In this case, the main challenge is to adequately choose the distribution of observations in homogeneous categories.

The variables and their categories to build the control sample are shown in Table 3.

TABLE 3
Variables and strata used in the Coarsened Exact Matching

Variable	Strata
Size (number of employees)	10 to 29
	30 to 99
	100 to 249
	250 to 499
	500 to 999
	1,000 or more
Average wage	Inferior 25%
	25% to 50%
	50% to 75%
	Upper 25%
Sector (ISIC3)	15-19
	20-22
	23-25
	26
	27-29
	30-33
	34-35
	36
Firms that received fiscal benefits	1 - if yes
	0 - otherwise
Firms that received financial support	1 - if yes
	0 - otherwise
Firms that received grants	1 - if yes
	0 - otherwise

Source: Own elaboration.

We have chosen to control by size according to IBGE's strata, splitting the upper stratum into two, one from 500 to 999 employees and the other for firms with 1,000 or more employees. We decided to include a variable to control for

employees' capabilities. PINTEC does not hold information on level of education, neither does the PIA. Thus, we chose average wage as a proxy for employees' capabilities and split the sample into four basic strata. We also control for differences in technological opportunity and appropriability, including sectoral variables as of Table 3. Finally, as presented in Figure 3, some firms that participate in PPI are also treated by other policies. We found it important to control for the effects of other policies on innovative effort and included these variables into the matching exercise (GUERZONI; RAITIERI, 2015; UYARRA, 2012). We purposely have not included other innovative characteristics as control variables, because they may be influenced by PPI, which may confound their effect on innovative efforts.

3.3 The model

Figure 4 shows the intervention logic of innovation policy. First, one applies the instrument, then a change in conduct is expected. After, changes in performance with different time ranges may occur. In this paper, we are interested in understanding the influence PPI has on innovative effort. This option derives from the limited time frame available (only one PINTEC).[4] We have chosen the ratio of private R&D expenditures to sales as the effort variable to be evaluated. This variable is bounded on the lower side at zero and on the upper side at one, that is, it may assume a value of zero with positive probability and is a continuous variable up to one, resulting on corner outcomes in both cases.[5] To handle this feature, we applied a tobit instead of an OLS model. Thus, we estimated:

$$\frac{private\ R\&D}{sales}i = \mathbf{x_i}\boldsymbol{\beta} + \mu_i | \mathbf{x_i} \sim Normal\,(0,\sigma) \qquad (1)$$

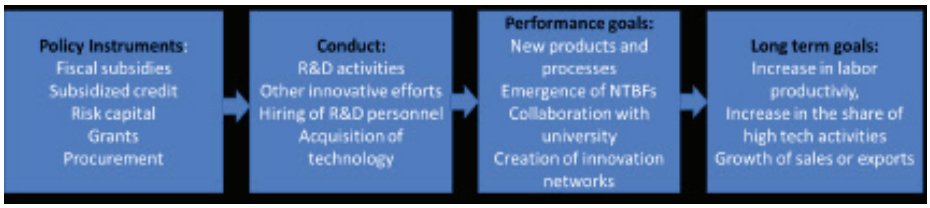
$$\frac{private\ R\&D}{sales}i = \max\ 0, \left(\frac{private\ R\&D}{sales}\right) \qquad (2)$$

where $\frac{private\ R\&D}{sales}i$ is a latent variable that linearly depends on a vector of firm and sector characteristics, $\mathbf{x_i}$, which is supposed to be normally distributed and $\frac{private\ R\&D}{sales}i$ is the observable dependent variable.

4 As has been said above, PINTEC 2014 is the only edition to inquire about PPI. The next PINTEC will be carried out from information for 2017 collected in 2018 and made available in the end of 2019. When we had access to the PINTEC microdata, the 2015 PIA was not available yet.

5 We have excluded all observations with R&D intensity over 1.

FIGURE 4
Intervention logic



Source: Adapted from Cunningham, Gök and Laredo (2013).

The independent variables are firm size, measured by the natural logarithm of the number of employees, average wage and a set of policy variables that should control for the use of other policies. To test the effect of policy designs on the outcome, we have decided to include variables for each policy instrument and interaction variables with procurement.

4. Results and discussion

Table 4 presents the results for the tobit regressions. Equations (1) and (2) differ with respect to the introduction of a quadratic form for the size variable (lnsize2). Equation (3) includes variables representing other policy instruments used by firms and interaction variables between PPI and these instruments. Equation (4) reproduces equation (3) with the addition of the quadratic form variable for size.

In equations (1) and (2), PPI is positive and significant at the 5% level, suggesting a positive effect of PPI on private R&D intensity of little more than 3 percentage points. This is more than one standard deviation of the whole sample (see Table 2). The size variable (lnsize) in equation (1) assumes a positive sign, significant at the 5% level. When one includes the quadratic form for size in equation (2), lnsize reduces its value but increases its significance. The quadratic form assumes a negative and significant sign, suggesting a concave function. Its maximum value occurs when firms are larger than 100 thousand employees and no firm in manufacturing and mining has this size. Average wage has a positive sign that is significant at the 10% level in both equations (1) and (2).

When we introduce variables representing other policy instruments, PPI becomes more significant (1% level) and increases its impact on private R&D intensity to almost 6 percentage points, that is, more than twice the standard deviation of the whole sample of firms. This probably occurs due to higher R&D disbursements in firms that are treated by other instruments more focused on R&D activities. Thus,

once we account for this bias, the impact on R&D intensity increases. Nonetheless, the only other policy variable that maintains a positive and significant value is credit for innovative activities.[6] The size variable in equation (3) remains positive but loses significance to the 10% level. In equation (4) the size variables have the same sign and similar values to equation (2).

TABLE 4

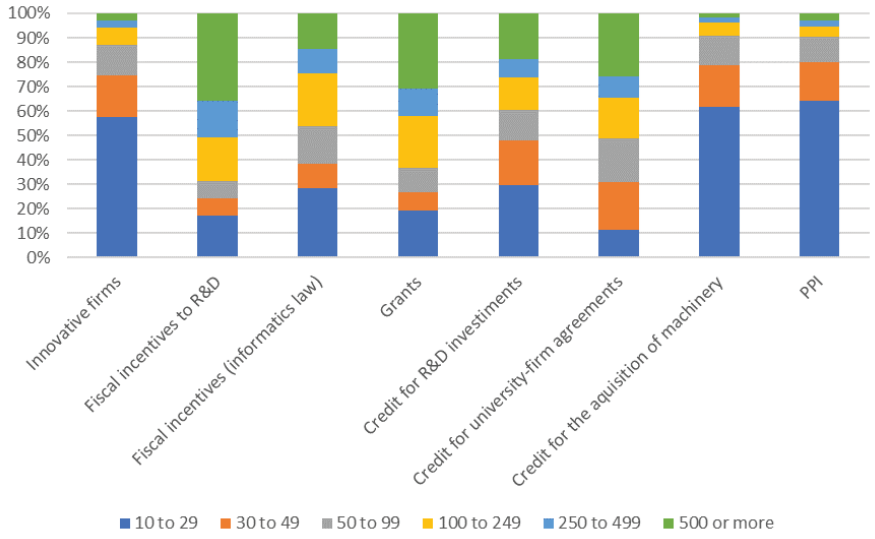
Tobit regressions

	(1)	(2)	(3)	(4)
PPI	0.0338**	0.0305**	0.0599***	0.0595***
	(0.0147)	(0.0146)	(0.0214)	(0.0213)
lnsize	0.0160**	0.108***	0.0123*	0.107***
	(0.00615)	(0.0397)	(0.00675)	(0.0396)
lnsize2		-0.00760**		-0.00786**
		(0.00321)		(0.00318)
Average wage	0.000372*	0.000378*	0.000139	0.000143
	(0.000215)	(0.000210)	(0.000221)	(0.000216)
Financial			0.0466*	0.0448*
			(0.0265)	(0.0260)
Fiscal			0.0351	0.0410
			(0.0305)	(0.0299)
Grants			0.0138	0.0115
			(0.0269)	(0.0265)
PPI*financial			-0.0344	-0.0326
			(0.0352)	(0.0344)
PPI*fiscal			-0.00874	-0.0213
			(0.0381)	(0.0377)
PPI*grants			-0.0207	-0.0151
			(0.0361)	(0.0356)
Constant	-0.147***	-0.404***	-0.151***	-0.420***
	(0.0343)	(0.118)	(0.0382)	(0.120)
Sigma	0.0692***	0.0677***	0.0670***	0.0653***
	(0.00689)	(0.00671)	(0.00663)	(0.00643)
Observations	132	132	132	132
chi2	26.48	32.33	38.95	45.32
N_unc	57	57	57	57
N_rc	0	0	0	0
N_lc	75	75	75	75

Source: Own elaboration, using PINTEC (2014).
Standard error in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

6 Although financial resources for innovative activities is the only significant variable for other policies, this does not mean that any of these policies is altogether ineffective. The inclusion of these policy instruments in the regression have the only purpose to control for the effect of these instruments on R&D.

FIGURE 5
Distribution of firms that received governmental support per instrument and firm size – 2012-2014



Source: IBGE, PINTEC (2014).

The results suggest an important role of PPI in incentivizing firms' innovative efforts, even when controlling for the presence of other policies. The analysis of this result should be accompanied by three other important perceptions. First, firms involved in governmental procurement that promote innovation have successfully been able to expand their R&D effort. This may be related to the building of absorptive capacity to capture externally-produced knowledge, that is, the PINTEC questionnaire asks whether firms have used public procurement to enhance innovative activities. The firms that stated they had used it spent more on R&D than those that stated they had not used public procurement. This can be explained by the need to perform complementary activities.

Second, Brazilian innovation policy has had trouble in targeting small and medium-sized firms. An analysis of the policy instruments enrolled by PINTEC shows that large firms are more easily targeted by innovation policy instruments than others (Figure 5). This phenomenon has been identified in other analyses, such as ABDI (2013, p.101),[7] that states in its conclusions that innovation policy in

7 ABDI (2013) may be viewed as the most thorough governmental effort to assess innovation policy results. The document does not, however, cover procurement policy, neither the use of public funds to the acquisition of equipment and machinery with innovative purposes.

Brazil has mostly targeted large firms, which were already innovative and high-R&D performers. The sole exception is the use of subsidized credit for the acquisition of machinery and equipment. However, the acquisition of machinery is a supply-dominated action which has little impact on capability accumulation. The ability of public procurement to reach small firms is a fairly important characteristic to help overcome obstacles to target smaller firms and should be welcomed in the policy mix. This ability has been stressed in the literature (ROTHWELL, 1984; ASCHHOFF, SOFKA, 2009; ROCHA, 2017). Moreover, the identification that public procurement of innovation promotes R&D expenditure not only denotes the building of absorptive capacity, but it also stresses the role of PPI in promoting the accumulation of learning and capability. This is even more important when one understands that Brazil suffers from structural heterogeneity. Highly productive firms appear in the same environments as very low-productivity firms and one main driver of this characteristic is the uneven diffusion of knowledge and innovation (PINTO, 1970). Innovation policies should therefore account for this shortcoming of the Brazilian production structure.

The third perception is a consequence of a systemic view of the innovative process. Policy should promote interaction between agents and procurement policies have this characteristic. It can foster information flows across firms and governmental enterprises and agencies. This is even more important when dealing with small firms. Rocha (2017), analyzing oil and gas suppliers to Petrobras, was able to identify that the most important effect of PPI was to induce small firms to perform R&D efforts. Furthermore, it supplied information on best practices and obliged firms to follow quality-control programs. In the case of procurement of innovative goods, the exchange of information was crucial for a successful outcome. PPI supplies the tools for this type of interaction, and foremost in the case of small firms that do not have access to international markets.

Although some sectoral strategic initiatives have been carried out both before and after Law no. 12349/2010, there is no clear policy for the use of PPI in Brazil (MOURÃO; CANTU, 2014). The results from this paper encourage one step further towards the formulation of a thorough policy that: may adequately identify targets for the use of PPI (and, in this case, be aware of the potential benefits for small and medium-sized enterprises); is able to integrate PPI to other innovation policy instruments; and builds policy capabilities to manage instruments correctly (KATTEL; LEMBER, 2010).

5. Conclusions

The aim of this paper was to assess the effect of PPI practices on firms' private R&D expenditures, holding the hypothesis that PPI has played a positive role in incentivizing firms to perform innovative efforts. PPI includes initiatives directly related to bringing about solutions not present in the market context before it takes place, the use of innovation-friendly practices to foster the production of new goods and services, or the establishment of conditions conducive to firm capacitation and interactive learning.

The paper used data from the Brazilian Innovation Survey (PINTEC), which allowed the identification of the mining and manufacturing firms that were involved in PPI. We then built a control sample using coarsened exact matching and tested the effect of PPI on firms' private R&D to sales ratio. The results show that firms do increase their R&D intensity. Data also shows that most firms involved in PPI are small and belong to low-technology sectors.

Although the sample used is small (only 66 treated firms), some conclusions may be drafted from the study. The impressions collected in it disclose an important characteristic of PPI that had been previously emphasized by Rothwell (1984), among others: its ability to target small firms and contribute to local development. This is particularly true in a setting where there is a prevalence of high structural heterogeneity, as is the case of Brazil. Thus, PPI may be an important tool to stimulate interaction between the public and private sectors and to help overcome the uneven diffusion of technical progress.

The results calls for further research on the subject as well. First, the method did not allow the adequate discrimination of the cases framed into Law n. 12,349, which is perceived as a turning point in governmental procurement in Brazil. Second, although we carry out a description of the targeted firms' size and sector, further analyses on policy targeting and selection mechanisms are still necessary to adequately assess PPI and its potential to promote local development and the improvement of firms' innovative conduct. Third, an examination of public capabilities to adequately promote innovation is still necessary. In environments such as the Brazilian Health System, the Defense Industry, and the oil and gas sector, Brazilian agencies and state-owned companies have learned and accumulated capabilities to foster innovation in the interaction with the public sector. However, in other sectors, this is not necessarily true and further studies are necessary to understand the real potential of PPI to promote innovation widely.

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