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Is there an inverted-U relationship between competition and innovation in Brazil?

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Abstract

Using models that properly consider the non-linearity generated by the discontinuity of the dependent variable and the potential unobserved heterogeneity across firms, we investigate, for a sample of Brazilian companies, whether the relationship between innovation and competition is inverted U-shaped. Unlike most of the literature, we avoid using only investment in R&D as a measure of innovation, since firms in developing countries are less intensive in R&D (and other more sophisticated innovation activities) when compared with their developed counterparts. We confirm the inverted U-shaped pattern and find that, when compared with other innovation activities, the peak of the inverted-U curve is located relatively more to the left for spending in tangible assets. This validates previous evidence that competition affects innovative activities differently. Moreover, the relationship between competition and innovation turns monotonic and positive when we use a less granular sector classification, suggesting that the estimated relationship between both variables is sensitive to the aggregation level used to calculate the competition indicators.

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2. What do we Know About the Relationship Between Innovation and Competition?

Until the 1990s, most industrial organization theoretical models typically predicted a negative relationship between innovation and competition. However, in the last two decades, several theoretical contributions changed this view (e.g., Boone 2001, Aghion *et al.* 2005, Vives 2008, and Delbono and Lambertini 2022).[1] From a theoretical perspective, Aghion *et al.* (1997, 1999) advocate an inverted-U relationship between competition and innovation. This non-linear relationship is the result of the presence of both profit-maximizing companies and companies that face principal-agent problems in their management and are not profit-maximizing. The former firms reduce investment in innovation when competition increases, and the latter firms increase investment in innovation in response to more competition. In turn, for Vives (2008), the increase in the number of competitors reduces the residual demand of each company, reducing the incentive for innovation, but increases the elasticity of this residual demand, increasing investment in innovation. The combination of these two effects would generate the inverted-U shape pattern.

Moreover, Aghion *et al.* (2005) describe two additional opposite effects in action. On the one hand, more competition would reduce the rent to be captured by firms that are successful in their efforts to innovate, discouraging investment in this activity (the Schumpeterian effect). On the other hand, more competition would increase the incentive for firms to innovate to escape competition from their rivals (the escape competition effect). They also provide some empirical evidence confirming the inverted-U shape hypothesis. Similar theoretical results are also found if the model is expanded to allow entry (in all sectors) of foreign companies that are at the technological frontier (Aghion and Griffith 2005). Empirical evidence confirms this conclusion, especially regarding the inverted U-shaped relationship between innovation and competition arising from the entry of (domestic or foreign) new firms (Aghion *et al.* 2009).

Several empirical investigations for distinct sectors confirmed the U-shaped relationship between innovation and competition, and for companies both in developed (Tingvall and Podahl 2006, Tingvall and Karpaty 2011, Polder and Veldhuizen 2012, Askenazy *et al.* 2013, Bos *et al.* 2013, Peneder and Wörter 2014, and Santos *et al.* 2018) and, more recently, in emerging countries (Friesenbichler and Peneder 2016, Crowley and Jordan 2017, Ambrozio and Sousa 2017, Dhanora *et al.* 2018, Montégu *et al.* 2020, and Benavente and Zuniga 2022). Cincera *et al.* (2024) also confirm the inverted-U pattern for a multi-country sample of top corporate R&D spenders. Experimental evidence also points in the same direction (Aghion *et al.* 2018).

Nevertheless, there is also empirical evidence against the inverted-U relationship between innovation and competition. For example, Hashmi (2013) finds evidence of a negative relationship between both variables in a sample of American companies. The difference concerning the British case (Aghion *et al.* 2005) may be due to UK industries being more technologically neck-and-neck than their US counterparts. Correa and Ornaghi (2014) also investigate firms from the United States but find a positive relationship between patents and competition. They explain the absence of an inverted U-shaped relationship by the presence of a well-defined intellectual property rights system. Correa (2012) uses the same dataset as Aghion *et al.* (2005) and argues that the inverted-U-shaped impact of competition on innovation may result from the change in the UK patent protection system in 1982: there would be a positive relationship for 1973-1982 and no significant relationship for 1983-1994.

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[1] See Aghion and Griffith (2005), Schmutzler (2009), De Bondt and Vanderkerckove (2012), and Shapiro (2012) for reviews and discussions on this topic.

Mulkay (2019) uses a sample of French companies and finds a negative relationship between competition and both product and process innovation. On the other hand, Beneito *et al.* (2017) find a positive relationship between competition and patents in a sample of Spanish manufacturing firms. They explain this finding by incorporating the possibility of exit in their theoretical model. In turn, Benavente and Zuniga (2022) use instrumental-variable estimation and find a positive linear relationship between innovation and competition for Chilean firms, and a U-shaped pattern for Colombian companies.

Specifically for Brazil, Pires-Alves and Rocha (2008) find an inverted-U relationship between HHI and innovation. The same occurs in Correia and Moita (2011), who investigate the relationship between mark-ups and R&D expenditure. When the possible endogeneity of the competition measure is appropriately considered, this relationship loses statistical significance. However, both articles use a cross-section of Brazilian companies, which prevents them from adequately considering unobserved heterogeneity across firms.

In summary, as stated by Cincera *et al.* (2024), from an empirical perspective, the link between competition and innovation seems to be affected by the characteristics of the sample, the economic environment, and the indicators used for measuring both competition and innovation.

3. Methodology

3.1. Econometric Specification

We want to explain the innovative performance of companies based on the level of competition in their markets. More specifically, we want to investigate if there is an inverted-U relationship between competition (measured by the Herfindahl-Hirschman Index – HHI) and innovative activities, in which only a small proportion of the companies invest.[2] Therefore, the dependent variable has a null value for most of the observations as expected. In other words, it is convenient to estimate models of the type:

$$INNOVATION_{ijt} = \max\{0, \beta HHI_{jt} + \gamma HHI_{jt}^2 + \theta X_{ijt} + \alpha_t + \alpha_j + \alpha_i + \varepsilon_{ijt}\}, \tag{1}$$

where *i* indicates company, *j* indicates sector, *t* indicates year, *INNOVATION* is the monetary expenditure in innovative activities per worker (allocated to production activities), HHI is the Herfindahl-Hirschman Index, calculated for the industry (at the 3-digit level) to which the company belongs, X is a vector of control variables, and ε is a random error.[3] The other variables are parameters to be estimated.

In the model defined above, validation of the inverted-U relationship between innovation and competition requires $\beta > 0$ and $\gamma < 0$.[4] Furthermore, if the results confirm this pattern, the turning point from which competition begins to affect innovation efforts negatively is when HHI reaches the value of $-\frac{\beta}{2\gamma}$.

It is worth noting that most of the literature uses R&D investments (e.g., Tingvall and Podahl 2006, Askenazy *et al.* 2013, Friesenbichler and Peneder 2016, Crowley and Jordan 2017, and

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[2] According to the Oslo Manual (OECD/Eurostat 2018), "*innovation activities include all developmental, financial and commercial activities undertaken by a firm that are intended to result in an innovation for the firm*". Innovative activities refer to the innovation process, while innovation relates to the outcomes of this process.

[3] $HHI = \sum_i s_i^2$, where *s* indicates market share. The HHI is an index of concentration, that is, the higher its value, the lower the competition. Particularly, $0 \leq HHI \leq 1$ and the closer to zero (one), the closer to perfect competition (monopoly).

[4] To confirm the inverted-U shape, it is necessary to additionally check whether the turning point is within the limits of the observed values of HHI in the sample (Polder and Veldhuzen 2012).

Montégu *et al.* 2020) or the number of registered patents (e.g., Aghion *et al.* 2005, Correa 2012, Hashmi 2013, Correa and Ornaghi 2014, Beneito *et al.* 2017, and Santos *et al.* 2018) as a measure of innovation. Nevertheless, patents are prevalent only in some industrial sectors, especially in more technologically advanced countries. And in developing countries like Brazil, few innovative companies are more intensive in R&D activities, and others, more numerous, that innovate by transforming existing technologies into new products and processes (Canêdo-Pinheiro and Figueiredo 2017). In many cases, these less sophisticated innovative activities can be a stepping-stone to advances towards world-class R&D activities (Bell and Figueiredo 2012). Therefore, restricting the analysis to R&D expenses implies ignoring many innovative activities.[5] Moreover, it is helpful to disaggregate the analysis by different categories of innovative activities, since there is evidence that competition affects them differently (Tang 2006). For those reasons, equation (1) is estimated for total expenditure in innovative activities and separately for spending on specific innovative activities, namely internal R&D, external R&D, investment in tangible assets (for innovation), and investments in intangible assets (for innovation) – see details in Table 1.

Table 1: Tangible and Intangible Assets

Tangible Assets	Intangible Assets
Equipment	Knowledge
Software	Training
	Marketing activities (internal or external)
	Other procedures and technical preparations

Notes: Both categories only include purchases for the implementation of product or process innovations. See Bukstein *et al.* (2019) for a similar categorization.

Some of the relevant literature uses binary indicators as a measure of innovation. For example, Crowley and Jordan (2017) use dummy variables indicating whether firms innovate, while Tang (2006) and Benavente and Zuniga (2022) use dummies indicating whether companies have positive expenditures in innovative activities. Nevertheless, this approach does not capture innovation intensity. We avoid this drawback by using expenditures on innovative activities as a metric of innovation.

The parameters in equation (1) cannot be consistently estimated by Ordinary Least Squares – OLS (Wooldridge 2002, pp. 524-525). The estimation method needs to appropriately consider the non-linearity generated by the discontinuity of the dependent variable. Under the assumption of normality of ε, equation (1) becomes a (Type I) Tobit model.

Furthermore, if there is unobserved heterogeneity across firms, endogeneity is a potential problem. If unobserved heterogeneity is time-invariant, firm fixed effects can alleviate this problem in linear models. However, the inclusion of fixed effects – α_i in equation (1) – in nonlinear models makes the estimators biased and inconsistent (Greene 2004). One possible strategy is to estimate the models with random effects, but this option is not suitable if the individual effects are correlated with the error term.

Considering that there is a correlation between the individual effects and the error term, it is possible to estimate the fixed effects as a function of the means (taken over time) of the individual variables ($\bar{X}_i$) and include them as additional controls in equation (1), as suggested in Zabel (1992). That is:

[5] The emphasis on relating innovation only to R&D is widely criticized in the literature, mainly because R&D data present only (part of) the inputs for innovation, but no output (Kleinknecht and Mohnen 2002).

$$\alpha_i = \eta \underbrace{\sum_{t=1}^{T} \frac{X_{it}}{T}}_{\bar{X}_i} + \varsigma_i, \tag{2}$$

where $\varsigma_i \sim N(0, \sigma_\varsigma^2)$ is supposed independent from ε_{it}.

3.2. Database

To estimate the model described by equations (1) and (2), we use microdata from different editions of the Brazilian Innovation Survey (PINTEC), elaborated by the Brazilian Institute of Geography and Statistics (IBGE). It is a sample survey, inspired by the Oslo Manual (OECD/Eurostat 2018), making it comparable to other similar surveys worldwide. We use five waves of this survey (2001-2003, 2003-2005, 2006-2008, 2009-2011, and 2012-2014), which enable us to construct an unbalanced panel of firms and to control the time-invariant non-observable characteristics.

PINTEC's sample is stratified according to firm size (number of employees), sector, state, and innovation potential. Firms with fewer than 10 employees are not surveyed, and larger firms (with 500 or more employees) are allocated in a specific stratum and selected with probability equal to one. The other firms are assigned to sampled strata, which were defined by crossing information on state and sectors. These strata (called natural strata) are then subdivided into two strata (called final strata), one with potential innovators and the other with the remaining firms.[6] The sample is disproportionately allocated, so that approximately 80% of the firms selected for the sample, in each natural stratum, are companies very likely to be innovative.[7]

Once PINTEC primarily focused on innovation-related information, we merged it with an additional survey from IBGE, the Annual Manufacturing Survey (PIA), to expand the set of available data on firms. PIA is compatible with PINTEC in methodological terms, such as the same sector classification, and covers all manufacturing and mining firms with 30 or more employees (smaller firms are sampled on a probabilistic basis).

Moreover, PINTEC was restricted to the manufacturing and mining sectors until the 2001-2003 survey. In the following surveys, the coverage was amplified to a few service sectors. In other words, given the PINTEC and PIA samples, the focus of this paper is mostly the manufacturing and mining firms with 30 or more employees.

Table 2 depicts some descriptive statistics for innovative activities. Brazilian manufacturing companies in our sample spend an average of R$769.18 per worker on R&D annually, most of it (R$657.40 per worker) in internal R&D. The most relevant innovative activities, at least in terms of expenditure, are investment in tangible (R$1,887.87 per worker) and investment in intangible assets (R$1,329.71 per worker). In total, companies spend an average of R$3,986.51 per worker on innovative activities annually. Moreover, as highlighted before, most companies are innovation-inactive: 36.1% invest in innovative activities, primarily in tangible (29.1%) and intangible assets (29.1%). Positive R&D expenditure is even less common: only 18.1% of the sample.

[6] In summary, potential innovators are defined by IBGE as firms that, in the survey period, were included in the registers of beneficiaries of innovation public policies or the Brazilian patent registers. The ones that were innovators in the previous surveys are defined as potential innovators as well.

[7] In natural strata where the total number of firms in the population is less than or equal to five, all firms are included in the sample with a probability of selection equal to one.

The control variables are the usual ones in the literature (Crépon *et al.* 1998). Table 3 presents some descriptive statistics for them. The sample contains 5% of foreign capital companies (*FOREIGN*), 10% are part of a business group (*GROUP*), and 17% are exporters (*EXPORT*). Moreover, on average, companies have 68 ($e^{4.22}$) employees (*SIZE*) and pay a monthly salary of R$11,328 per worker (*HUMAN CAPITAL*).

Table 2: Some Descriptive Statistics – Innovative Activities

Variable	Description	Mean (Standard Deviation) [% of non-zero]
INTERNAL R&D	Annual expenditure on internal R&D per worker allocated to production activities (R$ at constant 2016 prices)	657.40 (6332) [17.4%]
EXTERNAL R&D	Annual expenditure on external R&D per worker allocated to production activities (R$ at constant 2016 prices)	111.78 (3526) [5.2%]
R&D	Annual expenditure on (internal and external) R&D per worker allocated to production activities (R$ at constant 2016 prices)	769.18 (7.47) [18.1%]
TANGIBLE	Annual expenditure on tangible assets (see Table 1) for innovation per worker allocated to production activities (R$ at constant 2016 prices)	1,887.62 (4,298) [29.1%]
INTANGIBLE	Annual expenditure on tangible assets (see Table 1) for innovation per worker allocated to production activities (R$ at constant 2016 prices)	1,329.71 (10,790) [29.1%]
INNOVATION	Annual expenditure on innovative activities per worker allocated to production activities (R$ at constant 2016 prices)	3,986.51 (44,950) [36.1%]

Notes: Monetary values deflated by the Extended National Consumer Price Index (IPCA), calculated by IBGE.

Table 3: Some Descriptive Statistics – Control Variables

Variable	Description	Mean (Standard Deviation)
FOREIGN	Binary variable indicating companies with foreign capital	0.05 (0.23)
GROUP	Binary variable indicating companies that belong to a business group	0.10 (0.30)
SIZE	Logarithm of the number of employees	4.22 (1.02)
EXPORTER	Binary variable indicating companies that export	0.17 (0.37)
HUMAN CAPITAL	Monthly average salary per worker (R$ at constant 2016 prices)	11,328 (19,407)

Notes: Monetary values deflated by the Extended National Consumer Price Index (IPCA), calculated by IBGE.

4. Results

4.1. Main Results

Table 4 presents the results of the model described by equations (1) and (2) estimated for total expenditure in innovative activities. The first column depicts OLS results, and the second column (Type I) Tobit results. No relationship between innovation and competition is found when censoring is not adequately considered. However, the inverted-U relationship between both variables emerges when the model considers that most observations of the dependent variable are null. Furthermore, all control variables have the expected signs and are statistically significant. The turning point is achieved when the HHI is equal to 0.491. To illustrate the economic meaning of this result, note that $HHI = 0.500\ (0.250^2 + 0.250^2)$ when a market is equally divided between two firms. For comparison purposes, markets with an HHI greater than 0.180 or 0.200 are highly concentrated according to most antitrust authorities (e.g., European Commission 2004, DOJ and FTC 2023). Hylton (2024), for example, considers that markets with $HHI > 0.320$ are highly concentrated. In other words, the turning point occurs at a low level of competition.

Table 4: Innovation × Competition – Total Expenditure on Innovative Activities

	OLS	Tobit
β	10.612 (18.292)	98.333*** (29.669)
γ	-1.402 (22.221)	-100.230*** (34.277)
Turning Point $\left(-\frac{\beta}{2\gamma}\right)$	3.784 (53.770)	0.491*** (0.036)
FOREIGN	2.998 (2.466)	10.378*** (2.986)
GROUP	-0.481 (0.407)	6.996*** (1.827)
SIZE	-1.046** (0.493)	8.271** (3.353)
EXPORTER	0.627 (0.872)	12.379*** (3.703)
HUMAN CAPITAL	0.000 (0.000)	0.000** (0.000)
Observations	49,280	49,280
Firm Effects	YES	YES
Sector Effects	YES	YES
Year Effects	YES	YES

Notes: Table presents results from models described by equations (1) and (2). The dependent variable is expenditure per worker on all innovative activities (see Table 2). Parameters β and γ are associated with *HHI* and HHI^2, respectively – see equation (1). All models include (omitted for convenience) constant, time and sector fixed effects, firm fixed effects (in the OLS model), and random firm effects [in the Tobit model – see equation (2)]. The standard deviations of the estimated parameters are presented in parentheses. The symbols *, **, and *** indicate parameters statistically different from zero at 10%, 5%, and 1% significance level, respectively.

In turn, Table 5 shows results estimated for expenditure in distinct categories of innovative activities. All results are estimated in a (Type I) Tobit framework. The results resemble the second column of Table 4. The inverted U-shaped pattern persists, and the turning point is almost the same for all categories. That is, unlike the previous literature (Tang 2006), there is no evidence that competition affects distinct innovative activities differently.

4.2. Some Extensions and Robustness Checks

4.2.1. Rescaling the Dependent Variable

We re-estimate the model described by equations (1) and (2) with an alternative definition of the dependent variable. Instead of *INNOVATION*, we rescale the dependent variable to be ln (1 + *INNOVATION*), where ln indicates natural logarithm. Note that the variable remains censored at zero and that, given the value of the parameters β and γ, the turning point does not change, it remains $-\frac{\beta}{2\gamma}$.

Table 6 depicts the findings: the inverted-U relationship remains valid. However, compared with the results in Table 5, the turning point becomes larger, more noticeably for expenditure in tangible assets (increase from 0.463 to 0.612).

Finally, comparing the turning point for expenditure in tangible assets with other categories, we confirm that competition affects innovative activities differently (Tang 2006), at least for this specification. Bonfatti and Pisano (2020) build a model in which the turning point of the inverted-U relationship should be located more to the left if credit constraints are less prevalent. Tangible assets are typically less subject to credit constraints than investment in R&D or intangible assets. In this regard, our evidence is an indirect confirmation of their conjecture.

4.2.2. Recalculating HHI at a 2-Digit Level Industry Classification

Table 7 presents results analogous to the ones in Table 5, but with the Herfindahl-Hirschman Index calculated at a 2-digit level industry classification (instead of a 3-digit classification). Although $\beta > 0$ e $\gamma < 0$ in all models, there is no inverted U-shaped pattern. Remember that $0 \leq HHI \leq 1$. Therefore, as the estimated turning point is always larger than one, the relationship between competition and innovation is monotonic. Particularly, the more concentrated the market is (less competition), the larger the expenditure per worker in innovative activities.

These results resemble findings from Benavente and Zuniga (2002), who investigated the relationship between innovation and competition in Chile and Colombia. For Chile, the competition index was calculated at a 2-digit level, while for Colombia, it was calculated at a 3-digit level. They found an inverse-U-shaped relation between both variables for Colombian firms, but a linear relation for their Chilean counterparts. It suggests that the estimated relationship between innovation and competition is also sensitive to the aggregation level used to calculate the competition indicators.

Table 5: Innovation × Competition – by Type of Innovative Activity

	R&D	Internal R&D	External R&D	Tangibl
β	52.527*** (7.363)	46.475*** (6.607)	39.475*** (13.530)	59.8 (24.9
γ	-52.932*** (8.942)	-47.886*** (8.090)	-40.557*** (15.389)	-64.6 (31.4
Turning Point $\left(-\frac{\beta}{2\gamma}\right)$	0.496*** (0.027)	0.485*** (0.025)	0.487*** (0.038)	0.4 (0.0
FOREIGN	4.625*** (0.830)	3.976*** (0.731)	3.562*** (1.356)	6.0 (2.3
GROUP	2.685*** (0.476)	2.290*** (0.397)	3.019*** (0.936)	4.7 (1.5
SIZE	3.391*** (0.428)	3.026*** (0.415)	3.392*** (1.073)	9.5 (4.1
EXPORTER	6.227*** (0.837)	5.345*** (0.738)	4.633*** (1.586)	10.4 (3.5
HUMAN CAPITAL	0.000** (0.000)	0.000** (0.000)	0.000** (0.000)	0.0 (0.0
Observations	49,279	49,279	48,164	49,
Firm Effects	YES	YES	YES	YE
Sector Effects	YES	YES	YES	YE
Year Effects	YES	YES	YES	YE

Notes: Table presents results from models described by equations (1) and (2) and estimated with a (Type I) Tobit approach. Th
worker on each of the innovative activities (see Table 2). Parameters β and γ are associated with *HHI* and *HHI*^{2}, respectively – se
for convenience) constant, time fixed effects, sector fixed effects, and random firm effects [see equation (2)]. The standard dev
parentheses. The symbols *, **, and *** indicate parameters statistically different from zero at 10%, 5%, and 1% significance le

Table 6: Innovation × Competition – by Type of Innovative Activity (Alternatively Defined Dependent

	R&D	Internal R&D	External R&D	Tangibl
β	7.465*** (0.569)	8.002*** (0.605)	9.905*** (1.113)	2.1 (0.4
γ	-7.455*** (0.857)	-8.236*** (0.955)	-9.115*** (1.782)	-1.7 (0.5
Turning Point $\left(-\frac{\beta}{2\gamma}\right)$	0.501*** (0.030)	0.486*** (0.030)	0.543*** (0.058)	0.6 (0.1
FOREIGN	0.906*** (0.079)	0.936*** (0.083)	1.001*** (0.158)	0.4 (0.0
GROUP	0.476*** (0.059)	0.508*** (0.060)	0.571*** (0.132)	0.2 (0.0
SIZE	0.122*** (0.022)	0.185*** (0.023)	0.225*** (0.054)	0.0 (0.0
EXPORTER	0.859*** (0.060)	0.962*** (0.062)	0.640*** (0.133)	0.29 (0.0
HUMAN CAPITAL	0.000** (0.000)	0.000** (0.000)	0.000** (0.000)	0.0 (0.0
Observations	49,279	49,279	48,164	49,
Firm Effects	YES	YES	YES	Y
Sector Effects	YES	YES	YES	Y
Year Effects	YES	YES	YES	Y

Notes: Table presents results from models described by equations (1) and (2) and estimated with a (Type I) Tobit approach. Th worker on each of the innovative activities (see Table 1). Parameters β and γ are associated with *HHI* and *HHI*^{2}, respectively – se for convenience) constant, time fixed effects, sector fixed effects, and random firm effects [see equation (2)]. The standard de parentheses. The symbols *, **, and *** indicate parameters statistically different from zero at 10%, 5%, and 1% significance le

Table 7: Innovation × Competition – by Type of Innovative Activity (HHI Calculated at a 2-Digit Leve

	R&D	Internal R&D	External R&D	Tangibl
β	21.122*** (2.783)	19.076*** (2.723)	12.879*** (3.812)	31.3 (13.
γ	-7.521*** (1.141)	-6.940*** (1.122)	-4.102*** (1.339)	-13.5 (5.9
Turning Point $\left(-\frac{\beta}{2\gamma}\right)$	1.404*** (0.056)	1.374*** (0.053)	1.570*** (0.116)	1.1 (0.0
FOREIGN	4.069*** (0.780)	3.468*** (0.674)	3.327** (1.328)	5.2 (2.0
GROUP	2.584*** (0.468)	2.204*** (0.392)	2.935*** (0.917)	4.5 (1.5
SIZE	3.397*** (0.433)	3.036*** (0.418)	3.408*** (1.091)	9.4 (4.0
EXPORTER	6.282*** (0.840)	5.384*** (0.738)	4.660*** (1.598)	10.5 (3.6
HUMAN CAPITAL	0.000** (0.000)	0.000** (0.000)	0.000** (0.000)	0.0 (0.0
Observations	49,279	49,279	48,164	49,0
Firm Effects	YES	YES	YES	YE
Sector Effects	YES	YES	YES	YE
Year Effects	YES	YES	YES	YE

Notes: Table presents results from models described by equations (1) and (2) and estimated with a (Type I) Tobit approach. Th
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parentheses. The symbols *, **, and *** indicate parameters statistically different from zero at 10%, 5%, and 1% significance le

5. Final Considerations

We investigate the relationship between innovation and competition using a panel database of Brazilian companies. We use models that properly consider the non-linearity generated by the discontinuity of the dependent variable and the potential unobserved heterogeneity across firms, finding robust evidence in favor of an inverted-U pattern, as theoretically predicted by Aghion *et al.* (2005).

From a methodological standpoint, and unlike most of the literature, we use expenditure in distinct innovative activities as measures of innovation. Such an approach is best suited for firms in developing countries, where corporate investment in R&D and patent activity – the more prevalent innovation measures used in the literature – are less prevalent when compared with developed countries. It also allows investigating whether competition impacts distinct innovative activities differently. In this regard, we found that the peak of the inverted-U curve is located relatively more to the left for expenditure in tangible assets. This finding, at least for some model specifications, confirms previous evidence that competition affects innovative activities differently (Tang 2006).

Furthermore, the relationship between competition and innovation turns monotonic and positive (instead of inverted U-shaped) when we use a less granular sector classification. This result resembles findings from Benavente and Zuniga (2002), and it suggests that the estimated relationship between innovation and competition, besides depending on the indicators used for measuring both competition and innovation (Cincera *et al.* 2024), is also sensitive to the aggregation level used to calculate the competition indicators.

From a public policy perspective, given the positive externalities associated with innovation and market failures related to credit constraints, there is room for public support for private innovation. In that regard, in the late 2000s and early 2010s, the Brazilian government substantially increased expenditures on tax incentives for innovation, R&D funding, and support for other innovative activities, and created new mechanisms to promote corporate innovation. As an illustration, nearly 5.3% of Brazilian manufacturing companies were covered by innovation support policies in 2000. In 2014, public funding for innovation reached 14.6% of these companies (Canêdo-Pinheiro and Figueiredo 2017). However, the results were modest.

Simultaneously, several industrial policies were also implemented in Brazil, many of them implying a more protected domestic market (Canêdo-Pinheiro 2015). Our results indicate that less competition can lead to less innovation. Therefore, the potential positive effect of public support for innovation may have been offset by the negative impact of industrial policy on competition, especially in markets where competition was already low. That is, to maximize the positive effect on innovation, it is necessary to harmonize the design of industrial and innovation policies, especially regarding negative impacts on competition. This policy prescription is particularly relevant considering that Brazil is quite closed to international trade (Canêdo-Pinheiro 2014) and given Brazilian fiscal constraints (World Bank 2022).

Finally, from a theoretical perspective, the turning point of the inverted-U relationship should be located more to the right if credit constraints are more prevalent (Bonfatti and Pisano 2020). Most innovation surveys, including the Brazilian, contain questions about innovation obstacles, especially financial obstacles. There is a well-established empirical literature on the impact of financial barriers, as well as knowledge and market obstacles, on innovation.[8] However, there is scarce literature on the interaction of innovation obstacles, particularly credit constraints, with the relationship between competition and innovation. In this regard, this could be an

[8] See Moraes Silva and Vonortas (2022) for references on this topic, including regarding the Brazilian case.

interesting avenue for future research, remarkably in the Brazilian context, where innovation barriers are quite relevant (Cabral *et al.* 2020).

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