Innovative Efficiency Under Financial Constraints: Perspectives from a Semi-parametric Approach

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Abstract

The effect of financial constraints on Research and Development (R&D) has been widely studied due to the unique challenges of financing innovation. While some studies suggest financial constraints reduce R&D investment, others propose they may enhance innovative efficiency by forcing firms to focus on their most promising projects. This paper uses a semiparametric approach to investigate the relationship between financial constraints and innovative efficiency. Our findings reveal that smaller, younger, and more financially constrained firms exhibit higher innovative efficiency. The relationship is positive, significant, and non-linear, indicating that financial constraints can drive firms to focus on high-potential projects. However, for larger and more mature firms, the effect of financial constraints decreases. These insights suggest that financial constraints may impose a need on firms to improve their performance by overcoming agency problems and optimizing R&D investments.

Keywords
Financial Constraints, R&D Investment, Innovative Efficiency, Semi-parametric Analysis, Agency Problems, Econometric Analysis

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1. Introduction

The effect of financial constraints on Research and Development (R&D) has received a great attention in the literature, specially because of the unique features involving innovation projects. Such things as asymmetric-information problem, uncertainty of its output, high adjustment costs and principal-agent problem are some of the many peculiarities of R&D that support the view that innovative projects are costly and difficult to finance with external resources (Hall, 2002; Brown et al., 2009; Hall et al., 2016).

Following this hypothesis, many empirical studies have been conducted exploring the relationship between investment in R&D and financial constraints (Hall, 2002; Bond et al., 2003; Brown et al., 2009, 2012; Hsu et al., 2014; Ayyagari et al., 2011; Czarnitzki and Hottenrott, 2011). Although some of the results appear to be controversial, the papers show that financial constraints directly affect the firm's level of R&D investment. This result holds specially for small and young firms in more high-tech intensive sector.

While this connection between financially constrained firms and R&D investment appear to be well explored in the literature, a few studies have suggested the existence of a potential benefit of financial constraints on innovation.

Contrary to the widespread idea that access to financial resources is a key determinant of innovation, empirical evidences have shown that a higher level of financial constraint may be associated with a higher level of innovative efficiency (Katila and Shane, 2005; Hoegl et al., 2008; Almeida et al., 2013; Merz, 2021).

The authors argue that large and established firms are highly subject to agency problems, which may affect the investment decision to a suboptimal level, particularly for innovation projects, that are high uncertain and intangible. Firm with excess of free cash flow may invest in less productive R&D projects that are out of their areas of expertise (Almeida et al., 2013).

On the other hand, financially constrained firms face high cost of capital and scarce availability of resources for innovation activities. As a result, constrained firms only invest in their most promising projects. Hoegl et al. (2008) also argue that under resource constraints, the innovation teams are more likely to recognize an unexpected and profitable idea. Thus, these firms can achieve a higher innovative efficiency.

Even though these few studies have already investigated the dynamics of innovative efficiency and how financial constraints could be related to it, just a small number of empirical analysis have been conducted. Since the output of innovation is what matters for making financial profit, investigating the firm's innovative efficiency may be a useful tool for guiding investment decisions. Thus, this paper aims to investigate the dynamics of the relationship between financial constraints and innovative efficiency by employing a robust econometric analysis using a semi-parametric approach.

Given the well established assumptions and its easy interpretation, the linear parametric model has been extensively applied in economics. However, the classical model assumes a constant coefficient for the explanatory variables, which may sometimes not be appropriate, leading to a potential model misspecification (Robinson, 1988). The semi-parametric analysis combines parametric and nonparametric modelling, allowing us to estimate the linear parameters and a graph representation of the non-linear element, which is given by a function of parameters.

As we are interested in analysing how financial constraints is related to innovative efficiency, we propose a partially linear model using Robinson (1988)'s square root of N consistent estimator. By adding our proxies for financial constraint in the non-linear component, we plot the relationship between the level of financial constraint and innovative efficiency.

Consistent with the work of Almeida et al. (2013), we find that smaller, younger and more financially constrained firms have, on average, a higher innovative efficiency. The shape between financial constraints and the coefficient on innovative efficiency is positive, significant and non-linear. The findings support the view that firms with more available resources is subject to agency problems and less productive R&D investment, lowering their average innovative efficiency. However, we also find that for very large, mature and low financially constrained firms the relationship between financial constraints and innovative efficiency becomes linear and constant. This unprecedented result shows that even though tightening financial resources to innovation may affect their innovative performance, after some level, this effect is mitigated as firms become very large, mature and little financially constrained.

This paper contributes to the literature that studies the dynamics of investment in innovation. Going on the opposite idea that lack of resources to R&D may impede many innovations of happening, we show that there is potential benefit from this limitation. The fact that financial constraints is associated with a higher innovative efficiency suggests that investors and managers could use financial restrictions as a tool to overcome agency problems and improve firm's innovative efficiency.

Including this introduction, this article is organized as follows: Section 2 describes the related literature on financial constraints and innovative efficiency. Section 3 describes the data, empirical model and the semi-parametric approach. Section 4 presents the empirical results and discussion. Section 5 concludes.

2. Brief literature review

The empirical investigation of the role of financial constraints on firm's investment was initiated with the seminal work of Fazzari et al. (1988) about the impact of financial market imperfections and differences in the access of firms to capital. The authors explore the hypothesis that "imperfect" capital markets[1] have difficulty to evaluate the quality of investment opportunities, thereby the cost of external finance may differ substantially from the cost of internal finance - generated by cash flows and retained earnings. Thus, the investments of firms that use almost all of their internal funds to invest should be very sensitive to cash flow shocks.

[1] Fazzari et al. (1988) refers to "imperfections" in capital markets mainly as the asymmetric information problems.

Despite of some criticism related to methodological problems on Fazzari et al. (1988)'s work, their empirical framework has widely been used and explored in different scenarios to identify and measure the impacts of financial constraints to physical investment (Kaplan and Zingales, 1997; Alti, 2003; Moyen, 2004; Almeida et al., 2004). Following the same approach, the method has also been evaluated to explore the presence of an even higher impact of financial constraints to R&D investments.

Bond et al. (2003) emphasize that intangible assets, such as R&D, tend to be more susceptible to financing constraints due to the fact that their are riskier and harder to collateralize. As a result, channeling external resources to innovation projects might be very expensive and R&D spending will be affected by the availability of cash flow if internal financing is the only accessible option for funding innovation projects (Czarnitzki and Hottenrott, 2011). As consequence of this constraint, potential R&D projects may be hampered, leading to lower levels of innovation (Brown et al., 2009, 2012).

Although this relation between financial constraints and R&D investment has widely been investigated by the literature, little attention has been given to the impact of financial constraints on innovative efficiency. We define innovative efficiency as the firm's capacity of generating patents and/or citations per dollar of R&D investment (Almeida et al., 2013; Hirshleifer et al., 2013).

R&D investment is an important measure of financial resources to innovation and it is commonly used as a proxy for innovation input. On the other hand, patents and citations are a common measure of innovation output because new products, services or processes are usually introduced to the market as approved patents (Griliches, 1990). Therefore, an improvement in innovative efficiency happens when less investment in R&D is required for the same amount of patents generated.

Following this idea, Katila and Shane (2005) examine a model of environmental conditions to explore whether lack of resources promotes or constraints innovation. They find that new firms were notably more innovative than established firms in highly competitive and small markets. Another study of Hoegl et al. (2008) propose that financial constraints act as a stimulus, rather than an inhibitor of innovation teams' performance by leveraging creativity, engagement, cohesion and team potency.

A later work of Almeida et al. (2013) investigate whether firms that are more likely to be constrained are associated with higher rates of innovative efficiency. By proposing an econometric model, they find that more constrained firms have more granted patents and citation per dollar of R&D. This relationship is stronger among firms with large cash holdings and low investment opportunities.

Merz (2021) study a contest model to investigate whether more financially constrained firms have higher ability of transforming investment in R&D into new technologies. Interestingly, he finds that for several scenarios, small firms have a higher or at least the same innovative efficiency level of large firms.

Overall, these findings indicate an important role of financial constraints in explaining firm's innovative performance. Our purpose is to further explore the drivers of this relationship between financial constraints and innovative efficiency by taking an robust empirical approach.

3. Data and Methodology

3.1. Data and empirical model

We construct our database by collecting financial indicators and patent-related data of publicly traded firms around the world from ORBIS[2], country-level measures from the Global Financial Development Database (provided by The World Bank Group, updated in September 2019), and R&D tax subsidies data from OECD Science, Technology and R&D Statistics (OECD, 2021).

From the intersection of these three databases, we get a sample of 1571 firms from 12 developed countries over the period 2009 - 2018. We select only manufacturing firms (SIC code 2000 - 3999) that report at least one year positive R&D expenditure and had at least one patent granted during the sample period.

Our main proxy for innovative efficiency is patents scaled by R&D expenses ($Patent_{it}/R\&D_{it}$). $Patent_{it}$ is the firm i's total number of patents granted in year t and $R\&D_{it}$ is the firm i's R&D expenses in year t. According to Almeida et al. (2013), contemporaneous R&D has a stronger effect on contemporaneous patent applications than in upcoming patents. Although, we also test alternatives measures of innovative efficiency using two years and one year gap between R&D and patent application, but we obtained similar results.

We use three measures of financial constraints: firm age (number of years since the first IPO), firm size (logarithm of total assets), and the WW index (Whited and Wu, 2006).Hadlock and Pierce (2010) emphasize that firm size and age are closely linked to the level of financial constraints, and these variables have the advantage of being much less endogenous than other firm characteristics.

The WW index was constructed by Whited and Wu (2006) using an estimation of an investment Euler equation. The index is based on six financial variables and is calculated as:

[2] Orbis is Bureau van Dijk's flagship company database that contains information on 300 million companies across the world and focuses on private company information.

$$WW_{it} = -0.091\Big(\frac{CF}{TA}\Big)_{it} - 0.062DDIV + 0.021\Big(\frac{LTD}{TA}\Big)_{it} - 0.044Size_{it} + 0.1021ISG_{it} - 0.035SG_{it} \quad (1)$$

where i is the firm, t is the year, CF is the cash flow; TA is the total assets; $DDIV$ is a dummy of dividends payment; LTD is the long-term debt; $Size$ is the natural logarithm of total assets; ISG is the industry's sales growth, and SG is the firm's sales growth.[3] By construction, as higher the value of the index, more financially constrained the firm is.

To correctly evaluate the effect of financial constraints on innovative efficiency, we also include a set of control variables, as suggested by Almeida et al. (2013). First, we include long term debt scaled by total assets (DE/TA) and cash flow (CF) to capture the effect of firm's capital structure and availability of internal resources on R&D and patenting activities. Also, market-to-book ratio (MTB) to control the effect of growth opportunities, and R&D expenses divided by sales (RDS), because it reflects R&D intensity and it may be positive related to operational performance. In addition, we control for country heterogeneity by adding the natural logarithm of GDP (LOG_GDP).

In light of this, we propose a semi-parametric partially linear model to capture the parameter heterogeneity of financial constraints in innovative efficiency, given by:

$$\begin{aligned} \frac{Patents_{it}}{R\&D_{it}} = \beta_1 * \frac{CF_{it-1}}{TA_{it-1}} + \beta 2 * SG_{it-1} + \beta_3 * \frac{DE_{it-1}}{TA_{it-1}} + \beta 4 * MTB_{it-1} + \\ + \beta 5 * RDS_{it-1} + \beta 6 * LOG\_GDP_{it-1} + f(FC_{it-1}) + u_{it} \end{aligned} \quad (2)$$

where i is the firm, t is the year, and FC is one of the three measures of financial constraints (size, age and WW Index). $\theta(\cdot)$ is a function of parameters, and u is the error.

3.2. Semi-parametric Approach

In empirical economics analysis, the classical parametric approach has been widely used and disseminated, given its easy interpretation and well established assumptions. However, the restriction of a constant coefficient for the explanatory variables may sometimes not be appropriate, leading to a potential model misspecification (Robinson, 1988).

To diminish this problem, Robinson (1988) propose a partially linear model that combines parametric and nonparametric modelling.

[3] Due to data availability, we don't have information about dividends payment and industry's sale growth. Therefore, we compute WW index using only four variables, which we believe will not affect our results.

A general semi-parametric model can be written as:

$$Y = \beta' X + f(Z) + u, \tag{3}$$

where X is a $1 \times q$ vector, β is a $1 \times p$ vector of unknown parameters, Z is a $1 \times p$ and f is an unknown real function.

Robinson (1988) provided a $\sqrt{N}$-consistent estimator for the parameters β in Equation 1, when Z is a stochastic function of arbitrary dimension. By using a two-step approach, he first takes the conditional expectation, leading Equation to

$$E(Y|Z) = \beta' * E(X|Z) + f(Z) \tag{4}$$

and by subtracting (2) from (1), we have

$$Y^* = \beta' X^* + u, \tag{5}$$

where $Y^* - E(Y|Z)$, $X^* = X - E(X|Z)$, and assuming that $E(u|Z) = 0$.

The estimation of β proceeds by performing kernel-based estimates of Y^* and X^*. After getting the values of $\hat{\beta}$, we can rearrange Equation 1 to directly estimate the unknown function $f(\cdot)$ using a Nadaraya-Watson estimator. We get

$$\hat{f}(Z) = \frac{1}{\hat{f}(Z)} + \sum_{i=1}^{n} K(\frac{Z_i - Z}{h})(\hat{Y}^* - \hat{X}^{*\prime}\hat{\beta}), \tag{6}$$

where $\hat{f}(Z) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{Z_i - Z}{h})$.

4. Empirical analysis and results

4.1. Summary Statistics

Table 1 reports the summary statistics of our main variables of interest. We provide the mean and standard deviation for all sample and for firms grouped by the level of innovative efficiency (low-high IE) and also by industry (low-high tech).[4]

To classify firms as low IE and high IE, we sort our sample according to the value of innovative efficiency, and then split them into quintiles. Firms in the first two quintiles were classified as being low IE, and firms located in the last two quintiles were classified as high IE. By looking at the values from Table 1, there are some particularly interesting numbers.

[4]The classification of industry is based on optimal three-digit SIC Code provided by Kile and Phillips (2009) to sample high-technology firms.

As expected, firms in the high IE group are much more innovative efficient than firms in the low IE group. The difference of the mean value of innovative efficiency between these two groups is about four times. The average value of sales growth of firms with high IE (0.090) is slightly bigger than the firms with low IE (0.055). Besides the small difference, it suggests that innovative efficiency may be positively associated with the firm's sales growth. It also can be noted that firms classified as high IE are better evaluated by the market, showing a higher market-to-book indicator. These firms also have higher levels of debt, indicating that greater efficiency would drive more demand for more capital to support higher financing innovation. The mean values of size, age and WW don't show a significant variation between the groups classified by the level of innovative efficiency.

Table 1: Summary Statistics

	All sample		Low IE		High IE		Low tech		High tech	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Innovative Efficiency	2.039	4.324	0.703	2.757	4.039	5.183	1.876	4.270	2.210	4.374
Cash flow/Total assets	0.025	0.154	0.025	0.151	0.031	0.154	0.046	0.123	0.003	0.178
Debt/Total assets	0.081	0.099	0.079	0.098	0.082	0.101	0.093	0.101	0.068	0.095
Sales Growth	0.068	0.232	0.055	0.223	0.090	0.244	0.051	0.206	0.086	0.256
Market-to-Book	2.202	1.904	2.056	1.828	2.449	2.024	1.762	1.592	2.664	2.088
R&D/Sales	0.109	0.160	0.103	0.156	0.115	0.163	0.056	0.116	0.165	0.181
Size	19.087	1.659	19.055	1.672	19.195	1.591	19.495	1.538	18.657	1.673
Age	16.322	7.908	16.272	7.877	16.885	7.986	17.493	8.238	15.088	7.349
WW Index	-0.881	0.077	-0.879	0.077	-0.887	0.074	-0.899	0.070	-0.863	0.079
Log(GDP)	28.214	1.034	28.251	1.019	28.216	1.063	28.360	1.003	28.059	1.043
Obs.	2632		1621		812		1350		1282	

	Small		Large		Young		Mature		High WW Index		Low WW Index	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Innovative Efficiency	3.134	5.358	1.264	3.165	2.470	4.914	1.712	3.784	3.060	5.306	1.258	3.093
Cash flow	-0.054	0.204	0.081	0.061	-0.015	0.189	0.061	0.100	-0.058	0.200	0.086	0.062
Debt/Total assets	0.072	0.100	0.099	0.101	0.081	0.100	0.079	0.094	0.073	0.101	0.095	0.099
Sales Growth	0.092	0.281	0.046	0.177	0.102	0.267	0.034	0.185	0.057	0.267	0.082	0.202
Market-to-Book	2.739	2.235	1.817	1.444	2.610	2.127	1.686	1.478	2.599	2.184	1.915	1.560
R&D/Sales	0.184	0.205	0.048	0.069	0.155	0.191	0.059	0.105	0.183	0.205	0.050	0.071
Size	17.400	0.994	20.701	0.625	18.508	1.688	19.721	1.431	17.434	1.029	20.656	0.725
Age	13.314	6.703	19.292	8.559	9.500	3.190	24.460	5.473	13.438	6.714	19.115	8.611
WW Index	-0.805	0.053	-0.953	0.027	-0.855	0.080	-0.909	0.065	-0.802	0.049	-0.955	0.025
Log(GDP)	27.957	1.006	28.412	0.996	28.104	1.007	28.389	1.024	27.989	1.010	28.413	0.993
Obs.	1053		1052		1183		1010		1052		1053	

By grouping companies in high and low tech sectors, we notice that firms with a higher technological degree have lower levels of cash, debt, are smaller and younger. These firms are also better evaluated by the market, with a greater market-to-book. The reduced liquidity level associated to lower debt level, smaller size and higher market-to-book indicator may suggest that these firms have good investment opportunities but insufficient resources to meet such demand.

4.2. Estimation results

Using the semi-parametric approach presented in Section 3, we estimate our model given by Equation 2. The estimation of the semi-parametric model using Robinson (1988)'s $\sqrt{N}$-consistent estimator allow us to obtain an estimation of the linear parameters (β) and a graphical representation of the non-parametric element ($f(\cdot)$).

We start our discussion by analyzing the estimated coefficients for the linear part of our semi-parametric model, and also by presenting the results of a parametric estimation, which is shown in Table 2.

As expected, debt has a negative and significant coefficient, highlighting that a high level of debt may affect firm's innovative performance. Consistent with Almeida et al. (2013), R&D intensity, captured by RDS variable, has a negative and significant effect on firm's innovative efficiency. Market-to-book (MTB) is not significant. Logarithm of GDP is negative and significant, suggesting that firms in bigger countries may have a lower innovative performance.

Table 2: semi-parametric regressions

	Pooled OLS			Semi-parametric		
	Size	Age	WW Index	Size	Age	WW Index
CF_{t-1}	-3.544***	-4.885***	-3.003**	-4.701***	-7.442***	-4.046***
	(1.074)	(1.045)	(1.149)	(0.820)	(0.741)	(0.914)
SG_{t-1}	0.983**	1.105**	1.463***	1.015**	1.024**	1.468***
	(0.369)	(0.367)	(0.376)	(0.354)	(0.363)	(0.356)
$(DE/AT)_{t-1}$	-2.033	-2.725*	-2.297*	-2.177**	-3.152***	-2.344**
	(1.167)	(1.170)	(1.170)	(0.843)	(0.835)	(0.834)
MTB_{t-1}	0.128*	0.160**	0.136*	0.0967*	0.154**	0.102*
	(0.0608)	(0.0606)	(0.0610)	(0.0476)	(0.0481)	(0.0476)
RDS_{t-1}	-3.657**	-2.789*	-3.715**	-4.995***	-4.957***	-5.159***
	(1.169)	(1.180)	(1.153)	(0.734)	(0.742)	(0.732)
LOG_GDP_{t-1}	-0.433**	-0.557***	-0.449**	-0.464***	-0.605***	-0.474***
	(0.136)	(0.141)	(0.137)	(0.0824)	(0.0826)	(0.0819)
$Size_{t-1}$	-0.498***			—		
	(0.105)			—		
Age_{t-1}		0.0993			—	
		(0.239)			—	
$WWIndex_{t-1}$			10.69***			—
			(2.396)			—
N	2632	2632	2632	2632	2632	2632
adj. R^2	0.091	0.070	0.091	0.031	0.064	0.036

Results of the linear coefficients of the semi-parametric model using Robinson (1988)'s $\sqrt{N}$-consistent estimator. Standard errors are reported in parenthesis. The superscripts ***, **, and * denote statistical significance at the 1%,5%, and 10% levels, respectively.

Turning now our analysis to the non-parametric element, which is the focus of our paper, Figure 1 presents the shape of the estimated relationship between innovative efficiency and the financial constraints proxies with 95% pointwise confident bands.

In the first graph of Figure 1, we observe a clearly descendant relationship between size (measured as the natural logarithm of total assets) and the coefficient on innovative efficiency. The downwards line indicates that bigger firms are associated with a statistically significant decrease in innovative efficiency. This pattern holds until approximately the logarithm of

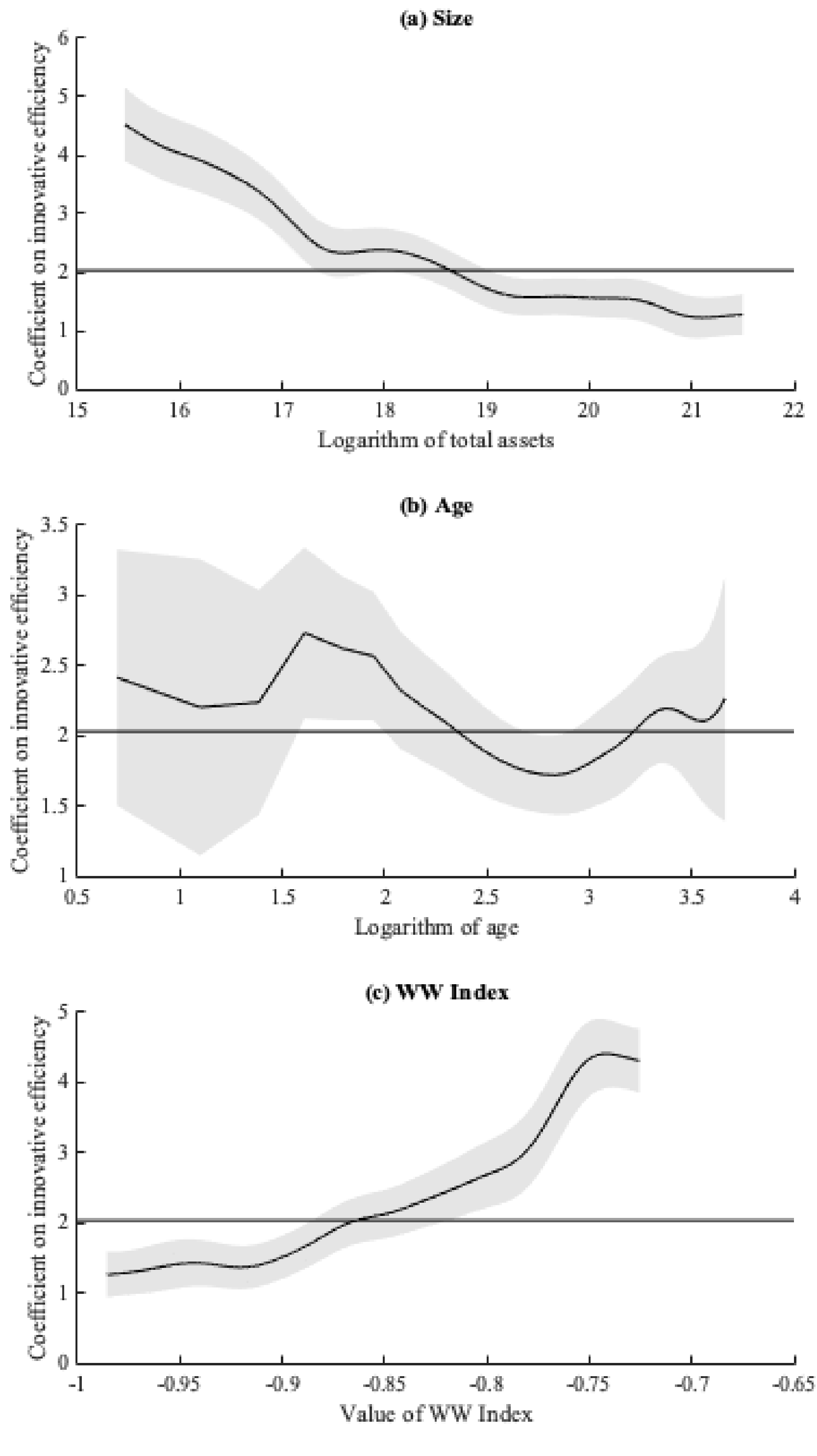

Figure 1: Estimated coefficient function on innovative efficiency for financial constraints measures and 95% pointwise confidence bands.

total assets equals 19 (U$170mi). After this size, the inclination of the function changes and become approximately constant, with the coefficient on innovative efficiency about 1.

The second graph brings the relation between age and the coefficient on innovative efficiency. Despite the large confident bands, we observe a negative inclination of the function until the value of logarithm of age of 2.5 (17 years). After 17 years, the line changes its direction and become slightly crescent.

In the third graph, the shape of the relationship between the level of financial constraint measured by WW Index and the coefficient on innovative efficiency begins approximately constant (about 1) until the value of the index gets to -0.9, and then the function becomes linear and ascendant. The construction of the index presumes that more financially constrained firms have a higher value of the index. Therefore, the estimated function shows that, on average, more financially constrained firms have a statistically higher average innovative efficiency.

The above results indicate that the presence (and degree) of financial constraints is positively associated with innovative performance. Consistent with the work of Almeida et al. (2013), who previously evidenced this relationship.

The primary explanation to understand why more financially constrained firms have a higher innovative efficiency is the decreasing returns to scale in R&D activity. As pointed out by Almeida et al. (2013), firms with excess of free cash flow are more susceptible to make sub-optimal R&D investment decisions, especially in innovation projects where the level of uncertainty is high. On the other hand, financial constraints require firms to cut costs because they have to compensate the resources that they can not get on financial markets, which make them to invest only in their in their most potential innovation projects. Merz (2021) argue that innovative efficiency is a "lever" with which financial constrained firms can overcome its low stimulus to innovate, by producing more valuable patents with lower financial resources.

Although this positive and significant relationship between financial constraints and innovative efficiency has already been discussed and suggested by the literature, our results also point to a non-linearity in the way that financial constraints affects the dynamic of innovative efficiency. As already introduced, all the three graphs of Figure 1 present a change in the inclination of the function for firms with lower financial constraints. This change of pattern in the function suggests that after some level financial constraints does not have an effect on innovative efficiency.

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5. Robustness

To check the robustness of our results, we run a number of sensitivity tests, and we present two of the most important checks. First, we estimate our model using an alternative proxy for innovative efficiency. As proposed by Hirshleifer et al. (2013), we measure innovative efficiency as the ratio of a firm's patents scaled by its 3-year cumulative R&D expenses assuming an annual depreciation rate of 20%.[5]

Figure 2 presents the graphical results of the estimated coefficient function of our proxies for financial constraints on the alternative measure of innovative efficiency. It is possible to notice that we obtain very similar pattern of results comparing to those of Figure 1. There is a difference in the magnitude of the values of the coefficient, but the shape of the function remains consistent with our previous findings.

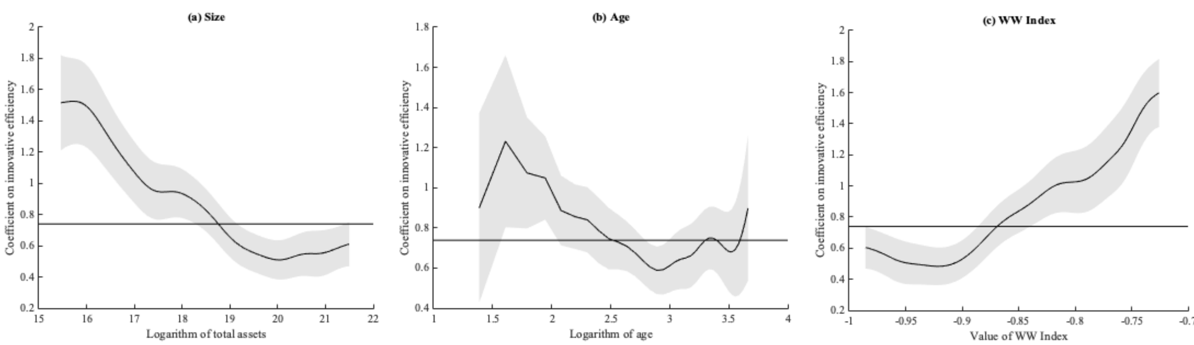

Figure 2: Estimated coefficient function for financial constraints measures and 95% pointwise confidence bands using alternative measure of innovative efficient.

Second, we estimate our baseline model splitting firms according to their industry sector (low-high tech), as we did in Table 1, following the optimal three-digit SIC Code provided by Kile and Phillips (2009) to sample high-technology firms. Results are shown in Figure 3. The general shape and magnitude remains very close to those of Figure 1 for both industries. It is worth to notice, however, that there is change in the pattern of results for small and more financially constrained (higher WW index) firms in low tech sector, which present a high decrease in the average innovative efficiency. The finding is consistent with the view that low tech firms with lower financial resources may not have the same motivation to innovate when comparing to those firm in more high tech sectors.

[5]Hirshleifer et al. (2013) use 5-year cumulative R&D expenses, but we use only 3-year cumulative R&D due to our short panel.

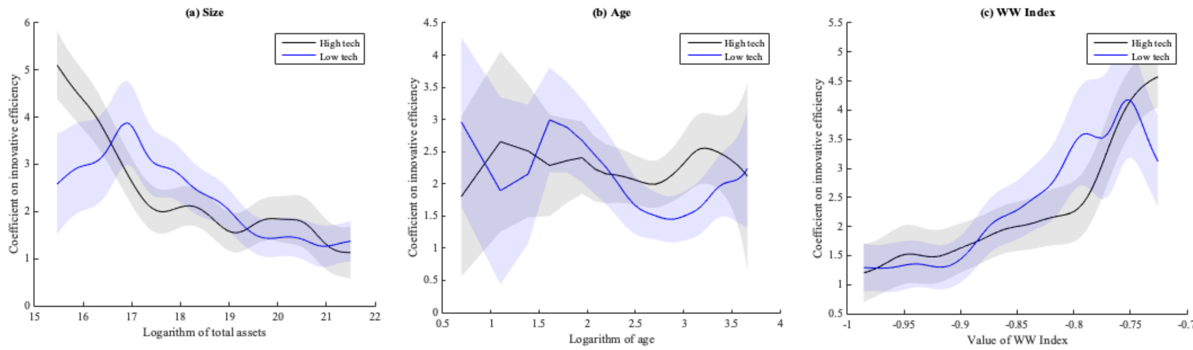

Figure 3: Estimated coefficient function for financial constraints measures and 95% pointwise confidence bands.

6. Conclusions

This paper investigates the dynamics of the relationship between financial constraints and innovative efficiency using a robust econometric analysis with a semiparametric approach. By employing a partially linear model, we analyze how financial constraints influence firm's innovative efficiency. Our findings reveal that smaller, younger, and more financially constrained firms exhibit higher innovative efficiency. The relationship between financial constraints and innovative efficiency is positive, significant, and non-linear. This supports the view that firms with abundant resources are prone to agency problems and less productive R&D investments, reducing their average innovative efficiency. In contrast, for very large, mature, and less financially constrained firms, the relationship becomes linear and constant, indicating that the effect of financial constraints diminishes as firms grow and mature.

Our results contribute to the literature by challenging the conventional belief that financial constraints hinder innovation. Instead, we show that financial constraints may impose a need on firms to improve their performance by overcoming agency problems, optimizing R&D investments and improve firm performance. The graphical analysis further supports our findings, showing a descending relationship between firm size and innovative efficiency, a negative relationship between firm age and innovative efficiency up to a certain point, and a positive relationship between financial constraints and innovative efficiency.

In conclusion, our study highlights the complex and nuanced relationship between financial constraints and innovative efficiency. Although financial constraints can drive firms to focus on high-potential projects, the benefits of such constraints are reduced for larger and more mature firms. These insights have important implications for policymakers and managers aiming to optimize R&D investments and enhance innovative performance.

This paper explores the intricate dynamics between financial constraints and innovative efficiency through a robust econometric analysis using a semiparametric approach. By employing a partially linear model, we examine how financial constraints shape firms' innovative efficiency. Our findings reveal a positive, significant, and non-linear relationship between financial constraints and innovative efficiency, particularly among smaller, younger, and more financially constrained firms. This suggests that resource deficiency forces these firms to mitigate agency problems and optimize RD investments, enhancing their innovative performance.

Interestingly, our analysis indicates that for larger, more mature, and less financially constrained firms, the relationship becomes linear and constant, implying that the impact of financial constraints reduces as firms grow and mature. Graphical analysis further supports these findings, showing a decreasing relationship between firm size and innovative efficiency, a negative relationship between firm age and innovative efficiency up to a certain point, and a consistent positive relationship between financial constraints and innovative efficiency.

These results challenge the conventional perspective that financial constraints uniformly hamper innovation. Instead, they reveal that such constraints can serve as a driver for firms to prioritize high-potential projects and improve resource allocation. However, the benefits of financial constraints appear to diminish for larger and more established firms, suggesting a threshold beyond which financial constraints no longer motivate efficiency.

Our study provides interesting insights for policymakers and managers. For policymakers, the findings highlight the need to design financial policies that support smaller and younger firms without providing excessive financial support to larger and established firms. For managers, the results underscore the importance of leveraging financial constraints as an opportunity to refine R&D strategies and enhance innovative outcomes.

While this research advances understanding of the relationship between financial constraints and innovative efficiency, further studies could explore how external factors such as market conditions, industry dynamics, or technological advancements influence this relationship.

In conclusion, this study underscores the complex relationship between financial constraints and innovative efficiency, providing a new perspective on how resource limitations can drive firms to innovate more effectively. These findings contribute to the literature and offer practical insights for optimizing R&D investments and promoting innovation.

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