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R&D, fixed capital investment and firm growth in Brazil

P&D, investimento em capital fixo e crescimento das empresas no Brasil

Luiz Alberto Esteves[a]

Abstract: The aim of this study is to gauge the impact of the production of knowledge on the accumulation of fixed capital in Brazil. The hypothesis is that investment in *R&D* causes investment in fixed capital in Brazilian industrial firms. The empirical estimates rest on an IPEA database for information on firms and the workers linked to these firms during the period 1996-2003 and on the National Innovation Survey (PINTEC) for information on technological development. In the article, various estimates are made using three empirical procedures. First, the firms that grew most and invested most are described. Second, econometric models relating *R&D* expenditures, technological innovation and the accumulation of fixed capital are estimated. A model having five equations and a structure similar to that of CDM models is estimated. The system employs instrumental variables to correct for endogeneity and solves the selection problem by including a firm-survival equation. Third, the causal relations between *R&D* and investment in fixed capital are sought through contrafactual analysis and a difference model. The results support the initial hypothesis, indicating that investments in *R&D* lead to an average 17% increase in investments in fixed capital among Brazilian firms.

Keywords: Firm growth. Knowledge production. R&D. Innovation. Simultaneous equation models.

JEL Classification: C31. C24. L60. O31. O32.

RESUMO: O objetivo deste artigo é avaliar o impacto da produção de conhecimento tecnológico das empresas brasileiras sobre sua acumulação de capital fixo. A hipótese do trabalho é que uma maior produção de conhecimento tecnológico, decorrente de maiores gastos em P&D, pode demandar das empresas uma expansão do capital fixo que viabilize a aplicação comercial deste novo conhecimento. A análise empírica é conduzida a partir de um banco de dados construído pelo IPEA, com informações de empresas e de seus respectivos trabalhadores, para o período de 1996-2003. A análise empírica é construída a partir de três procedimentos. Em primeiro lugar, a relação entre investimentos em P&D e capital fixo é conduzida a partir da análise de estatísticas descritivas. Em um segundo momento, utiliza-se modelagem econométrica para computar o efeito da inovação e do P&D sobre a acumulação de capital físico. Estes modelos econométricos são construídos a partir de um sistema de equações em uma estrutura semelhante à dos modelos CDM. O sistema emprega variáveis instrumentais para corrigir a simultaneidade entre investimentos em P&D e em capital fixo e propõe a correção do problema de seleção de painéis balanceados de empresas por meio de uma equação de sobrevivência. Em terceiro, as relações entre investimento em P&D e em capital fixo são exploradas através de análise contra factual, usando modelo de diferenças-em-diferenças. Todos os resultados corroboram a hipótese endereçada no trabalho.

Palavras-chave: Crescimento da Firma. Produção de Conhecimento. P&D. Inovação. Modelos de Equações Simultâneas.

Classificação JEL: C31. C24. L60. O31. O32.

[a] Doutor em Economia pela Universidade de Siena, Itália Professor do Departamento de Economia da UFPR. Professor do Programa de Pós-Graduação em Políticas Públicas da UFPR. E-mail: <esteves@ufpr.br>.

1 Introduction

There is relatively broad consensus among economists that the economic growth of nations is linked to technological innovation. Agreement narrows, however, when the issue is how to innovate. It is reasonable to assume that firms in developing countries partly innovate by purchasing capital goods, usually imported from developed countries. In turn, the technology embodied in this machinery and equipment allows for technological innovation on the part of these firms.

Nonetheless, such general interpretations of the economic dynamics of developing countries often mask the specific features of economies far different from one another. Brazil has approximately 180 million inhabitants and a fairly large industrial sector in which the 80 thousand firms with 10 employees or more engage more than 6 million workers and invest roughly USD 3 billion per year in *R&D*. Although these indicators differentiate Brazil from the majority of developing economies, the technological innovation indicators of the country are still far removed from those of developed economies and of the emerging Asian nations. While about 30% of the firms are innovative in Brazil, the corresponding average stands at 50% in the countries in the European Union. In 2003, Brazilian firms invested 0.6% of their revenue in *R&D*. In Germany and France, the percentages were 2.7% and 2.5%, respectively. In the same year, only 2.8% of the Brazilian industrial firms performed product innovations for the market. Moreover, of the 28,036 innovative firms, only 177 (0r 0.6%) innovated for the world market.

Does encouraging firms to invest in *R&D* cause them to invest in fixed capital and thereby accelerate their growth? Since the question is relevant for any country wishing to migrate to the more advanced stages of economic development, this article tests the hypothesis that the *R&D* investment of firms increases their rate of investment in fixed capital in Brazil. Verification of this hypothesis is important from the standpoint of public policy, for should it prove true, it would imply that, amongst other economic measures, the government should program higher investments aimed at stimulating *R&D* within firms.

Why might stronger investment in the *R&D* of firms lead firms to invest more in fixed capital? What might underlie the causal relation? The answer is that when a firm invests in creative activities, in knowledge and in *R&D*, it generates new products and processes that need to be produced and introduced on the market. The manufacturing and marketing activities of the firm therefore have to be adapted to its innovations. To this end, the firm makes additional investments in fixed capital to expand or adapt its production facilities, thus spurring the growth of the firm.

The information used to test this hypothesis covers 23,892 Brazilian firms between 1996 and 2003, representing more than 95% of total industrial value added in the period. The database was organized by the Institute for Applied Economic Research (IPEA) and contains information from other Brazilian government databases on firms and the workers connected to these firms. The information on the technological innovations of firms is from the National Innovation Survey of the Brazilian Industrial Sector (PINTEC).

In the second part of this article, descriptive statistics are presented on the firms that grew most and invested most in Brazil in the period extending from 1996 to 2003. In the third, econometric models correlating investments in *R&D* and in fixed capital are estimated, with attempts being made to correct any problems caused by selection or endogenous variables. In the fourth, the econometric models are directed towards identifying causal relations between *R&D* and fixed investment. In the fifth and final part, the conclusions of the study are presented.

2 What are the Characteristics of the Firms that Grew Most in Brazil?

To analyze the characteristics of the firms that grew most in Brazil during the period 1996-2003, the firms surveyed were placed in one of four quartiles according to their rates of growth. The quartiles were designated as follows: 1) low growth, 2) low average growth, 3) high average growth and 4) high growth. Growth was defined as the growth rate of firm revenue in relation to the growth rate of the revenue of the industrial sector to which the firm belonged in the period 1996-2003. The industrial sectors corresponded to those listed in the Brazilian National Classification of Economic Activity (CNAE) at the three two-digit level. The firms having been

Table 1 – Characteristics of Brazilian firms by rate of growth, 1996-2003

Firm growth	Turnover (R$ millions)	Labor productivity (R$ thousand)	Export Firms (%)	Innovative Firms (%)	Average schooling of labor force (years)	Innovation investment /Turnover (%)
Low	14.35	29.81	26	27	7.42	2.10
Low average	67.09	45.88	37	39	7.82	2.63
High average	69.40	57.90	45	48	8.16	3.04
High	72.12	60.83	47	48	8.25	3.38

classified, the following characteristics were considered with a view to determining which could be linked to the growth of enterprises: production scale, labor productivity, exports, innovation, investment in technological innovation and average schooling of the labor force. The results are presented in Table 1.

The findings reveal that production scale is smaller among firms that grow less within their industrial sectors. Likewise, the greater the productivity of labor, the higher the growth rate of firms. The data may therefore be pointing to positive correlations between scale and productivity and the growth of firms. In other words, the larger its production scale and the more productive its employees, the more likely a firm is to grow.

The size differentials across the four categories may indicate important competitivity differentials at the firm level. Whenever the increase in the output of a firm is more than proportional to the increase in the factors of production used, the firm experiences increasing returns to scale. In the presence of such returns, the increase in the size of the firm raises the overall productivity of its factors of production. However, the fact that the differences in labor productivity are more accentuated than the differences in scale may be indicating that the rise in the productivity of labor is tied to factors other than those linked to scale. Among these factors, technological innovation and the export performance of firms should be highlighted.

The percentages of both innovative and export firms are higher in the two groups of firms that also registered faster growth. As Araújo (2007) has shown, in addition to being more productive, firms that engage in foreign trade become more productive due to efficiency gains arising from the knowledge they acquire in the course of their activities. Thus, as the indicators confirm, firms that innovate and export more also grow more.

The indicators referring to the average schooling of the labor force employed by Brazilian enterprises show that those with more qualified labor register higher growth rates. Schooling is an especially relevant variable when analyzing the competitive strategies of firms since it serves as a proxy for the technological level of a firm, it being only reasonable to assume that higher-tech enterprises require more qualified labor. In turn, firms that hire such labor are in a better position to differentiate products and guarantee their quality. At the same time that more qualified labor broadens the options available to firms, it also strengthens the competitive position of the firm by allowing it to operate at a higher technological level.

With regard to technological innovation in relation to revenue, the indicators demonstrate that the firms that make the strongest innovation efforts are the ones that grow at the fastest pace.

But does the firm that invests in R&D invest more in fixed capital? In an attempt to answer this question, the investment indicators from a PINTEC panel referring to 3,130 firms in 2000 and 2003 were analyzed. The findings on the fixed investments of firms that made *R&D* investments are outlined in Table 2.

Table 2 – Average fixed investment of Brazilian firms* in accordance with *R&D* investment, 2000-2003

Variable	All firms	Firms that always invest in *R&D*	Firms that occasionally invest in *R&D*	Firms that never invest in *R&D*
Fixed investment per worker (R$)	40,225 (180,842)	63,545 (150,000)	33,517 (54,309)	33,196 (199,834)
Fixed investment/ net revenue (%)	21 (36)	24 (38)	23 (54)	19 (33)
Profit per worker (R$)	13,939 (354,456)	49,275 (354,456)	3,583 (241,442)	3,309 (291,181)

Standard error in parentheses. * Panel of firms included in the PINTEC, 2000 and 2003.

The descriptive statistics show that firms that invest in research and development, whether always or occasionally, inevitably have higher rates of fixed investment than firms that never invest in *R&D*. On turning to investments per worker, the investment level of firms that always conduct *R&D* is seen to be 90% higher that that of firms that do so only occasionally or never. In the case of fixed investment relative to net sales revenue, while no significant difference exists between firms that always invest in *R&D* and those that invest only occasionally, the level of both is 25% higher than that of firms that never invest in *R&D*. Lastly, firms that always invest in *R&D* have profits that are 14 times higher than those of firms that occasionally or never make *R&D* efforts.

In sum, the data have traced the characteristics of the firms that achieved the highest growth rates in the period 1996-2003. The firms that grew most were also the most productive. Likewise, firm growth was apparently linked to scale, exports, innovation, schooling of the labor force and investment in innovation activities. Firms that invested in *R&D* invested more in fixed capital than those that did not. This means that not only the growth of firms, but the growth of the Brazilian economy, may be tied to innovation and to the investment in knowledge.

3 The Knowledge Production Function and the Accumulation of Fixed Capital

The preceding analyses based on descriptive statistics serve to delineate the data and identify variables that may be associated with investment and the growth of firms. However, they do not take the heterogeneity of firms into account. To obtain more robust findings, several econometric estimates were therefore prepared to ascertain what leads a firm to invest in fixed capital. Three econometric models were estimated.

In the first model, the fixed investment of the firm as a percentage of its net sales revenue and its fixed investment per worker in the period 2000-2003 were regressed as functions of the innovativity of the firm. In accordance with the hypothesis of this study, this specification is aimed at establishing a statistical correlation between investment and innovation. Other explanatory variables used to specify the model include production scale (number of workers), profit margin (profit as a percentage of net sales revenue) and average schooling of labor force, as well as control dummies for export firms, multinational enterprises, industrial sectors and production locations. Several factors were expected to lead some firms to invest more than other firms, for example: larger firms to invest proportionately more than smaller firms; higher profit margins to strengthen the propensity to invest; a more qualified labor force to be associated with a stronger inclination to invest and; competitive factors linked to exposure to world markets, as in the cases of export firms and multinational enterprises, to stimulate investment.

The explanatory variables in the second model are the same as in the first, except that the innovation variable has been removed and a variable for firms that always or occasionally invested in *R&D* introduced.

The third model is a system containing two equations estimated in two stages. In the first equation, the probability of a firm investing in fixed capital is modeled as a function of its having invested in *R&D* continuously or occasionally. The other explanatory variables are production scale, average schooling of labor force and controls for export firms, multinational enterprises, sector and location. In the second equation, fixed investment as a percentage of net sales revenue and fixed investment per worker are regressed as functions of the same variables employed in the first model and also as functions of the estimated probability of a firm being innovative.

Equations estimated using these procedures do not correct for endogeneity problems, nor do they clearly define causality relations from the empirical standpoint. No questions arise, however, as to the statistical significance of the correlations between the variables. In addition, the equation system in the third model corrects the selection bias resulting from the higher expenditures occasioned by the decision of a firm to invest in *R&D* in order to innovate. The results of the estimates are presented in Table 3.

In sum, the results of the first model indicate that firms that innovated either products or processes in the period 2000-2003 invested 24% to 31% more in fixed capital than firms that did not perform innovations, while the findings of the second model show that those that invested in *R&D* invested 9% to 13% more in fixed capital than those that did not.

Table 3 – Fixed investment of Brazilian firms: explanatory variables, 2000-2003

Independent variable	Model 1		Model 2		Model 3	
	Ln(INV/RLV) 2000-2003	Ln(INV/PO) 2000-2003	Ln(INV/RLV) 2000-2003	Ln(INV/PO) 2000-2003	Ln(INV/RLV) 2000-2003	Ln(INV/PO) 2000-2003
Constant	-2.58*** (-5.28)	4.33*** (8.13)	-2.60*** (-5.28)	4.46*** (8.11)	-2.52*** (-5.10)	4.57*** (8.29)
Ln of number of workers (2000)	0.16*** (5.62)	0.24*** (7.73)	0.17*** (5.43)	0.24*** (7.30)	0.15*** (4.66)	0.22*** (6.34)
Ln(π/RLV) 2000-2003	0.14*** (6.92)	0.34*** (17.74)	0.14*** (6.86)	0.34*** (17.61)	0.14*** (6.87)	0.34*** (17.62)
Firms that innovate (2000-2003)	0.24*** (4.18)	0.31*** (5.03)				
Firms that invest in *R&D* (2000-2003)			0.09** (2.17)	0.13** (2.99)		
Estimated probability of firm innovating[a]					0.35** (2.65)	0.50*** (3.49)
Export firms (2000)	0.09 (1.34)	0.31*** (4.99)	0.09 (1.31)	0.31*** (4.32)	0.08 (1.17)	0.30*** (4.13)
Multinational Firms (2000)	0.25** (2.38)	0.49*** (4.21)	0.25** (2.30)	0.48*** (4.10)	0.24** (2.24)	0.47*** (4.03)
Average schooling of labor (2000)	-0.002 (-0.12)	0.07*** (3.55)	-0.0001 (-0.01)	0.07*** (3.56)	-0.005 (-0.27)	0.06*** (3.16)
Sector (2-digit SIIC)	Yes	Yes	Yes	Yes	Yes	Yes
Location (state)	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.26	0.54	0.25	0.53	0.25	0.53
F	4.96	16.43	4.82	16.15	4.84	16.21
N	1.835	1.860	1.835	1.860	1.835	1.860

*** Significant at 1%, ** significant at 5%, * significant at 10%, t-statistic in parentheses. INV = investment, RLV = net sales revenue, PO = number of workers.

[a] **Table 3** (cont.) – Probability of firm innovating, 2000-2003

Explanatory variable	Dependent variable
	Innovative firm (2000-2003)
Constant	-0.20 (1.42)
Ln of number of workers (2000)	0.03*** (3.74)
Firm invests in R&D (2000-2003)	***0.31*** (26.03)***
Export firms (2000)	0.02 (1.20)
Multinational firms (2000)	0.017 (0.59)
Average schooling of labor force (2000)	0.01** (2.14)
Sector (2-digit CNAE)	Yes
Location (state)	Yes
R^2	0.32
F	11.7
N	3.219

*** Significant at 1%, ** significant at 5%, * significant at 10%, t-statistic in parentheses.

In the third model, the equation system indicates that firms that invested in *R&D*, compared to those that did not, spent 10.8% more on fixed capital as a percentage of their net sales revenue. The investment in fixed capital per worker was also 15.5% higher among firms that invested in research and development.[1]

To further extend the analysis, we shall now propose a structural model relating *R&D* expenditures, technological innovation and the accumulation of fixed capital. The idea is to use a knowledge production function in which *R&D* expenditures are inputs and innovation is the tangible output of knowledge.

In the majority of empirical studies, the variable used for firm growth is the growth rate of the number of workers employed by the firm. However, it would be perfectly justifiable to allow the growth rate of the stock of capital to stand for the growth of the firm. In this case,

[1] In the regressions in the third model, the effects of *R&D* on investment are obtained indirectly by multiplying partial derivatives as follows:

$$\frac{\partial \sum_{t=2000}^{2003} \frac{INV_t}{RLV_t}}{\partial Inova} \frac{\partial Inova}{\partial R\&D} = 0.35 * 0.31 = 0.108 \quad \text{and} \quad \frac{\partial \sum_{t=2000}^{2003} \frac{INV_t}{PO_t}}{\partial Inova} \frac{\partial Inova}{\partial R\&D} = 0.50 * 0.31 = 0.155$$

the firm growth function would be specified as follows:

$$LnK_t = f\left(K_{t-1}, P\,\&\,D_{t-1}, X_{t-1}\right) \tag{1}$$

where LnK_t is the natural log of the stock of capital in period t, $P\,\&\,D_{t-1}$ is the natural log of *R&D* expenditures in period t-1 and X_{t-1} is a vector of explanatory control variables for the firm in period t-1. Another way to specify the firm growth function would be:

$$LnK_t = f\left(K_{t-1}, INOV_{t-1}, X_{t-1}\right) \tag{2}$$

where $INOV_{t-1}$ is a variable specifying whether or not the firm conducted a process or product innovation in period t-1.

Both of these growth function specifications lead to highly restrictive hypotheses. In equations (1) and (2), the technological variables present error orthogonality. In equation (1), R&D expenditures are considered to have direct impacts on the growth of the firm and the estimate may cause selection bias.

The knowledge production function originally developed by Griliches (1979) contributes to understanding these constraints by suggesting that *R&D* expenditures are inputs, while innovation is the output of the knowledge generated by the firm. In other words, *R&D* expenditures are not necessarily transformed into tangible results in the form of new products or processes. Furthermore, should *R&D* spending be inefficient, it may not have any effect whatsoever on the accumulation of capital. An example of the latter is provided by the case of a firm that invests in *R&D* to innovate a product that requires the acquisition of new machinery and equipment the firm is unable to purchase.

The most recent generation of these models was developed by Crépon, Duguet and Mairesse (1998). The idea behind CDM models is to provide a system of equations for explaining the relation between the growth of knowledge and productivity, while simultaneously correcting for endogenously and selection biases in the structure of the system. The CDM system is specified by the following equations:

$$dR\&D = f(X^1) \tag{3}$$

$$R\&D^* = f(X^2) \tag{4}$$

$$INOV = f(R\&D^*, X^3) \tag{5}$$

$$q = f(INOV^*, X^4) \tag{6}$$

where *dR&D* are:

$$dR\&D = 1 \quad \text{if} \quad R\&D = \beta_0 + \beta X^1 + \varepsilon^0 > 0 \tag{7.1}$$

$$dR\&D = 0 \quad \text{if} \quad R\&D = \beta_0 + \beta X^1 + \varepsilon^0 \leq 0 \tag{7.2}$$

Equation (3) is a probit estimate of the decision of a firm to invest in *R&D* and X^1 is a vector comprised of the variables that explain the decision. In equation (4), *R&D** is a latent variable, where:

$$R\&D = R\&D^* = \beta_0 + \beta_1 X^2 + \varepsilon^1 \quad \text{se} \quad dR\&D = 1 \tag{8.1}$$

$$R\&D = 0 \quad \text{se} \quad dR\&D = 0 \tag{8.2}$$

The errors ε^0 and ε^1 are assumed to have a bivariate normal distribution with mean 0, variance $\sigma^2_\varepsilon=1$ and correlation coefficient $\rho_{\varepsilon\varepsilon}$. These two equations are included in the system to correct for the selection bias caused by the decision of the firm to invest in *R&D*.

Equation (5) is the knowledge production function, the input being estimated *R&D* and the output being innovation. Lastly, equation (6) stands for the firm productivity function, where the explanatory variable $INOV$ is obtained through the knowledge production function.[2]

Lach and Rob (1996) argued that CDM models consider knowledge and fixed capital within the context of a neoclassical production function in which the factors of production have substitution and complementarity properties, thus making it difficult to establish causality relations between *R&D* investment and fixed investment. They therefore developed a model, closer to the hypothesis underlying the present study, suggesting that when ideas become innovations, they have to be implemented using new machinery and equipment, which leads to additional investment in fixed capital.

In this study, innovation and fixed investment are related through an equation structure similar to that developed for the CDM model. However,

[2] For a detailed presentation of the CDM model, see Crépon, Duguet and Mairesse (1998). A survey of the major empirical studies based on the CDM model is available in Hall and Mairesse (2006). Variations of the model have been estimated for France (DUGUET, 2000), Sweden (LÖÖF; HESHMATI, 2002), Germany and Sweden (JANZ; LÖÖF; PETERS, 2004), Holland (VAN LEEUWEN; KLOMP, 2006), Chile (BENAVANTE, 2006), China (JEFFERSON et al., 2006) and France, Germany, Spain and the United Kingdom (GRIFFITH et al., 2006).

given the focus of the analysis, a firm growth equation is used in place of the productivity equation. The system corrects for endogeneity by means of instrumental variables and solves the selectivity problem via inclusion of a firm survival equation. The decision to include this equation rests on the fact that the dependent variable is measured in terms of growth rates. However, it is not possible to guarantee that all the firms in the sample will survive the entire period and the loss of observations due to failure should not be considered a random phenomenon; rather, failure should be seen as the probability of firms having lower levels of investment in fixed capital, human capital, *R&D* and so forth. The equations to be estimated are:

$$dR\&D = f(X^1) \tag{9}$$

$$R\&D^* = f(X^2) \tag{10}$$

$$INOV = f(R\&D^*, X^3) \tag{11}$$

$$Survive = f(X^4) \tag{12}$$

$$\Delta k = f(INOV^*, X^5, Mills) \tag{13}$$

Equation (12) is the survival equation. This equation is used as an auxiliary regression to control the selection of firms that remain in operation throughout the period for which the growth rates of the stock of fixed capital are calculated. Finally, equation (13) is a firm growth equation similar to equation (2) but including a Mills inverse variable to control for selection and letting Δk stand for the growth rate of fixed capital.

Since the system developed by Griliches (1979) assumes full orthogonality between all system errors and the regressors of their respective equations, OLS estimation is possible. In contrast, the CDM model assumes that the entire system is comprised of nonorthogonal, correlated errors. The correlation coefficient $\rho_{\varepsilon\varepsilon}$ for any combination of errors in the equation system is therefore different from zero, making it necessary to estimate the system as a whole using, for example, Asymptotic Least Squares (ALS).

In this article, the error correlation structure is held to lie between that proposed by Griliches and by the CDM models. The hypothesis adopted follows that developed by Lööf and Heshmati (2002), which suggests (i) the explicit use of instrumental variables and (ii) the separation of the structure into two parts. In the model proposed herein, separating the error correlation structure rests on the hypothesis that there is no direct correlation between the errors in equations (9) and (10) and those in the growth equation (13).

The idea is that the variables omitted from the decision to engage in *R&D* in period *t* may be correlated with the decision to invest in period *t*. At this point, it should be recalled that the dependent variable in this study is the growth rate of the stock of fixed capital in period $\Delta k = (t+k)-t$. Thus, there is no inference as to any correlation between errors in the equation for engaging in R&D and firm growth. The argument is therefore analogous to using lagged variables as instruments.

The sample used to estimate the equation system covers 28,892 firms with 30 employees or more, among which: (1) 18,421 continued to operate without any change in ownership throughout the period under analysis; (ii) 3,830 diminished in scale and were excluded from the Annual Industrial Survey (PIA);[3] (iii) 1,526 ceased operations; (iv) 115 were purchased by other firms; and (v) 372 expanded their business through mergers and acquisitions. The distribution of firms according to these categories is relevant to the analysis of firm growth since: (i) information on the survival of firms in the period helps control for selection bias with respect to the growth of firms; and ii) the fact that a firm has expanded its stock of fixed capital through mergers or acquisitions is relevant when analyzing growth of the stock of fixed capital because the goal of this study is to isolate the impact of technological innovation on the growth of the fixed capital of firms.

The results based the equation system are reported in tables 4 through 7. The results for product innovations and product innovations were obtained separately and the growth equations were applied independently for two size classes: (i) smaller firms, or those having below average capital stock in 2000; and (ii) larger firms, or those having above average capital stock in 2000.

Estimating different regressions for different size classes is justified by the fact that it allows for testing alternate hypotheses as to the growth pattern of firms. According to Gilbrat's law, firm

[3] The PIA (Pesquisa Industrial Annual) surveys firms with 30 employees of more. When a firm decreases in size, it is removed from the census. This does not mean, however, that it has failed or been acquired by another firm.

growth is random under any circumstances, so the growth rate of a firm in period *t+1* is not influenced by the size of the firm in period *t*. However, the weak version of this law, originally developed by Simon and Bonini (1958), postulates that such randomness is observed only among firms that have already attained efficiency of scale.

In the estimates of the growth equations, firm age is included in the regressions as a means of testing the Jovanovic (1982) learning hypothesis, which assumes that younger firms have higher growth rates than older firms. The growth equations were estimated using two distinct econometric methods, 3SLS and FIML.

Table 4 – Determinants of decision of firm to invest and how much to invest in *R&D*, 2000

Independent variable	Dependent variable	
	Decision to invest in R&D (Probit model)	R&D per worker (Tobit model)
Competition (firm operates mainly in the domestic market)	-0.08 (0.09)	0.11 (0.16)
Cooperation (firm cooperates for innovation purposes)	-	0.39*** (0.07)
Number of patent applications in sector in which firm operates	1.14*** (0.07)	0.90*** (0.09)
Firm received public financing for innovation	0.57*** (0.07)	0.57*** (0.16)
Average schooling of workers employed by firm	0.08*** (0.01)	0.26** (0.11)
Firm attributes importance to government as source of information for innovation	-	-0.03 (0.06)
Firm attributes importance to suppliers as source of information for innovation	-	0.13 (0.11)
Firm attributes importance to universities as source of information for innovation	-	-0.11 (0.14)
Firm received government support for innovation	-	0.11* (0.07)
Firm attributes importance to customers as source of information for innovation	-	0.01 (0.09)
Firm attributes importance to competition as source of information for innovation	-	0.02*** (0.00)
Market share of firm	-	0.37 (0.50)
Market concentration in the sector in which the firm operates (HHI index)	-	0.19*** (0.02)
Scale of firm (number of workers)	Yes	-
Sector	Yes	Yes
Location	Yes	Yes
Constant	-1.82*** (0.49)	
RHO	0.58*** (0.04)	
Mills	0.87*** (0.08)	

*** Significant 1%, ** significant at 5%, * significant at 10%.

Table 5 – Determinants of probability of firm conducting product or process innovation, 2000

Independent variable	Dependent variable	
	Product innovation	Process innovation
Ln of estimated R&D per worker	0.65*** (0.03)	0.37*** (0.03)
Firm received public financing for innovation	0.02 (0.04)	1.02*** (0.05)
Firm attributes importance to government as source of information for innovation	0.51*** (0.06)	0.30*** (0.05)
Firm attributes importance to suppliers as source of information for innovation	0.23*** (0.02)	1.30*** (0.03)
Firm attributes importance to universities as source of information for innovation	0.55*** (0.06)	-0.07 (0.06)
Firm attributes importance to customers as source of information for innovation	0.82*** (0.03)	0.38*** (0.03)
Firm attributes importance to competition as source of information for innovation	0.37*** (0.03)	0.52*** (0.03)
Firm attributes importance to high costs as obstacle to innovation	-0.40*** (0.04)	-0.27*** (0.04)
Scale of firm (number of workers)	Yes***	Yes***
Sector	Yes***	Yes***
Location	Yes***	Yes***
Constant	-2.75*** (0.25)	1.51 (0.20)
R^2	0.28	0.29
N	15,905	15,909
χ^2	5,645***	6,255***

*** Significant at 1%, ** significant at 5%, * significant at 10%.

The determinants of the decision to invest in *R&D*, as well as how much to invest, precisely correspond to the variables used in studies based on the CDM model. However, an additional variable was included – average schooling of workers employed by firm – due to its being relevant to the decision as to whether or not and, if so, how much to invest in *R&D*.

The results of the *R&D* investment equation for Brazil are similar to those found by Griffith et al. for France, Germany, Spain and the United Kingdom. The only difference refers to the competition variable. In the four developed countries, firms focused on the international market are more likely to invest in *R&D*, with the level of statistical significance being less than 1%. Although the same was found for Brazil, when the equation was controlled by the schooling variable, the competition variable lost statistical significance. This means that the chance of firms engaging in *R&D* is determined not by the market in which it competes, but by the level of qualification of its employees.

Table 6 – Determinants of growth of stock of fixed capital of firm: product innovation, 2000-2003

Independent variable	Dependent variable					
	Ln of growth rate of stock of capital (2000-2003)					
	All surviving firms		Surviving firms with higher-than-average stock of capital for their sectors		Surviving firms with lower-than-average stock of capital for their sectors	
	3SLS	FIML	3SLS	FIML	3SLS	FIML
Ln of stock of capital in 2000	-0.04* (0.02)	-0.04*** (0.01)	-0.09 (0.09)	-0.07 (0.07)	0.16*** (0.06)	0.15*** (0.03)
Ln of (stock of capital in 2000)^2	-0.0009 (0.0009)	0.0009* (0.0005)	0.001 (0.02)	0.0006 (0.02)	-0.009*** (0.002)	-0.009*** (0.001)
Age of firm	-0.41** *(0.07)	-0.42*** (0.04)	-0.35*** (0.07)	-0.17*** (0.04)	-0.42*** (0.11)	-0.27*** (0.04)
(Age of firm)^2	0.05*** (0.01)	0.05*** (0.01)	0.04*** (0.01)	0.01 (0.01)	0.05*** (0.02)	0.03*** (0.01)
Product innovation estimate	0.17*** (0.03)	0.19*** (0.01)	0.13*** (0.02)	0.14*** (0.02)	0.19*** (0.05)	0.24*** (0.03)
Controls[c]	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.11		0.13		0.12	
F	16.54***		10.95***		8.05***	

*** Significant at 1%, ** significant at 5%, * significant at 10%.
[c] Controls: surviving firms that invested in fixed capital, average years of schooling, scale, selection on the part of surviving firms, sector and location.
[d] Instrumental variables for 3SLS and FIML: economic risks and lagged patent applications.

Table 7 – Determinants of growth of stock of fixed capital of firm: process innovation, 2000-2003

Independent variable	Dependent variable					
	Ln of growth rate of stock of capital (2000-2003)					
	All surviving firms		Surviving firms with higher-than-average stock of capital for their sectors		Surviving firms with lower-than-average stock of capital for their sectors	
	3SLS	FIML	3SLS	FIML	3SLS	FIML
Ln of stock of capital in 2000	-0.04* (0.02)	-0.04*** (0.01)	-0.09 (0.09)	0.15 *** (0.03)	0.15*** (0.06)	0.15*** (0.03)
Ln of (stock of capital in 2000)^2	-0.0009 (0.0009)	0.0008* (0.0005)	0.001 (0.002)	-0.009 *** (0.001)	-0.009*** (0.003)	-0.009*** (0.001)
Age of firm	-0.40*** (0.06)	-0.42*** (0.04)	-0.32*** (0.07)	-0.28*** (0.04)	-0.43*** (0.11)	-0.28*** (0.04)
(Age of firm)^2	0.05*** (0.01)	0.05*** (0.007)	0.03*** (0.01)	0.03 *** (0.008)	0.06*** (0.02)	0.03*** (0.008)
Process Innovation estimate	0.17*** (0.02)	0.17*** (0.01)	0.13*** (0.02)	0.21*** (0.02)	0.19*** (0.04)	0.21*** (0.02)
Controls[c]	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.12		0.13		0.12	
F	17.04***		11.21***		10.94***	

*** Significant at 1%, ** significant at 5%, * significant at 10%.
[c] Controls: surviving firms that invested in fixed capital, average years of schooling, scale, selection on the part of surviving firms, sector and location (state).
[d] Instrumental variables for 3SLS and FIML: economic risks and lagged patent applications.

The other variables all present signs and levels of significance similar to those found for the four European countries, that is: (i) larger firms have a stronger propensity to invest in *R&D*; (ii) firms that receive government financing are more likely to invest in *R&D* than firms that do not receive such financing; (iii) firms that operate in sectors in which patents are often used to protect innovations have a stronger propensity to invest in R&D; and (iv) firms that have better qualified labor are more likely to invest in *R&D*.

In the case of Brazil, the results of the equation as to how much to invest differ in certain respects from those for the developed countries. Once again, for Brazil, the international competition variable proved nonsignificant when the equation was controlled by the schooling variable, while the main market in which the firm operated stimulated investment in *R&D* in France and Germany. Firms that maintained cooperation agreements with other entities invested more in *R&D* in all five countries. However, whereas Brazilian firms operating in sectors that often use patents to protect their innovations invested more in *R&D*, this variable was not significant in any of the European countries considered. In Brazil, as in Germany and Spain, firms that received government financing tended to invest more in *R&D*.

Similar to the results found for the four European countries, the intensity of *R&D* proved highly significant both statistically and economically. Stronger *R&D* efforts per worker meant higher probabilities of success for both process and product innovation, though the impact was greater with respect to product innovation. While firms that received government financing were more likely to engage in process innovation, the same cannot be said of product innovation. This indicates that the incentives offered by the Brazilian government are directed to the purchase of machinery and equipment rather than to the accumulation of knowledge via *R&D*. With respect to the probability of Brazilian firms performing product innovations, all sources of information were important, with customer information standing out. With regard to process innovation, all sources contributed, except for universities.

As for the growth equations, in all the cases estimated, the product innovation variable presented parameters having positive, statistically significant signs. In comparison to the 3SLS estimates, the FIML estimates always had higher values for the upper parameters. It should be noted that, with respect to all the surviving firms, the parameters of the "Ln of stock of capital in 2000" variable had negative, statistically significant signs. These findings refute the hypothesis that growth of firms is a random process. Finally, it should be observed that the parameters of the "age of firm" variable also had negative, statistically significant signs, which confirms the hypothesis regarding learning by firms.

On analyzing the estimates for large and small firms, it is evident that the values of the parameters of the product innovation variable are higher for smaller enterprises. Likewise, the large firms, in contrast to the small firms, have nonsignificant parameters for the "Ln of stock of capital in 2000" variable. This suggests that the rate of growth of larger firms is a random process, thus confirming the weak version of Gilbrat's law. The findings support the learning hypothesis for both larger and smaller firms.

In overall terms, it can be concluded that firms that engaged in product innovation, in comparison to firms that did not, registered 13-24% higher growth rates in their stock of fixed capital. Among firms that conducted process innovations, the corresponding figure was in the 13-21% range. It was also verified that the difference in the growth rates of innovative and non-innovative firms was more marked among smaller enterprises than among larger ones.

4 Does *R&D* Cause Investment in Fixed Capital in Brazil?

In this section, the causal relation underlying the theoretical model presented in this article is approached from the empirical standpoint. The empirical literature on the investment determinants of firms was surveyed by Bond and Reenan (1999), who showed there is evidence of the causal relation between *R&D* investment and fixed investment in studies of developed countries. Most of the empirical evidence available is to be found in time-series analyses using the Granger causality test, such as those done by Chiao (2001) Lach and Rob (1996) and Lach and Schankerman (1989).[4]

To confirm the hypothesis that *R&D* investment drives the growth of a firm and spurs its investment in fixed capital, a two-step counterfactual analysis was performed.

In the first step, a panel of 15,694 firms from the 1996-2003 database was grouped in clusters according to similarities in their production processes and in the characteristics of their employees. The variables used to group the firms in clusters were: number of employees, revenue, investment in fixed capital, productivity (revenue/number of employees), wages, average schooling of employees, export coefficient (exports/revenue) and marketing expenditures. Three groups of firms were taken into account:

[4] Also see Nickell and Nicolitas (1996), Toivanen and Stoneman (1998) Pakes (1985), Griliches, Hall and Pakes (1991), Yang and Huang (2005).

(i) all manufacturing firms, (ii) innovative firms and (iii) firms in high-tech sectors.

In the second step, each cluster was divided into two groups: firms that invested in *R&D* and firms that did not invest in *R&D* in 2000. The investment and growth indicators of these groups were then analyzed for the period 1997-2003.

The aim of this procedure was to establish a causal relation via a counterfactual analysis. The firms were initially grouped according to the similarity of their production characteristics and subsequently accompanied over time so as to ascertain whether or not those that invested in *R&D* grew and invested more in their productive structures than other firms. If the firms had similar structural characteristics in 1997 and the only difference between them was that some invested in *R&D* in 2000 while others did not, it could be inferred that any differences in their growth and fixed investment patterns may have arisen partly due to *R&D* activities or the lack thereof. The findings of this counterfactual analysis are described in Table 8.

As the table shows, in 79% of the clusters, firms that invested in *R&D* invested more and grew more than firms that did not. The procedure adopted therefore supports the hypothesis that a causal relation exists between the two types of investment and that *R&D* therefore generates growth.

To turn these findings more robust and measure the impact of *R&D* and technological innovation expenditures on the growth of firms, the difference-in-difference method was used. This procedure, widely used to appraise public policies, consists in evaluating changes in the average behavior or performance of individuals before and after treatment and comparing these changes to a control group.

In this study, firms that innovated product and/or process were considered the "treatment group" and firms that innovated neither product nor process were considered the "control group." The performance measure to be tested was the investment by firms in fixed capital in the period before and after the innovation. The years 1996-1998 were held to comprise the previous period and 2001-2003 to constitute the subsequent period. Thus, the innovation variable fell in the period 1998-2000. All firms that remained in operation and had 30 or more employees between 1996 and 2003 were taken into account.

The first-order difference equation was specified as:

$$\Delta k_{i(t-1)-(t+1)} = f(INOV_t, X_{it}) \tag{14}$$

where $\Delta k_{i(t-1)-(t+1)}$ measures the difference in the fixed investment of the firm in the period preceding ($t-1$) and following ($t+1$) the innovation; X_{it} is the explanatory vector of firms *i* in period *t*; and $INOV$ is a dummy variable that assumes the value of 1 if the firm innovates in period *t* and zero if *it* does not.

Following Woldridge (2002), in order that the difference estimator be unbiased, it is assumed that policy changes and other factors that affecting *k* are not systematically related. By applying first-order differences, all the variables in the structural equation can be differentiated, thus controlling any existing heterogeneity.

Another robusticity analysis was performed on the basis of a panel sub-sample. In this analysis, equation (14) was once again estimated, this time including only those firms in the control and treatment groups that were similar in period *t*. The sub-sample was comprised of firms that were similar in 1998 with respect to scale, fixed investment, investment strategy, schooling of labor force, insertion in world markets, ownership of firm, sector and location. Propensity Score Matching (PSM) was used to pair firms. To test for robusticity, was carried out many alternatives for pars like neibours, 1 to K and Kernel. The findings are reported in Tables 9 and 10.

Table 8 – Number of clusters in which firms that invested in R&D also invested in fixed capital and registered higher or lower growth of revenue than firms that did not invest in R&D, 1997-2000

	Investment		Investment/ turnover		Growth of turnover		Total	
	Higher	Lower	Higher	Lower	Higher	Lower	Higher	Lower
All manufacturing firms	4	2	4	2	6	2	14	6
Innovative firms	5	1	5	1	8	0	18	2
Firms in high-tech sectors	6	1	5	2	6	2	17	5
Total	15	4	14	5	21	4	49	13

Table 9 – Difference-in-difference equation: product innovation

Independent variable	Dependent variable: Difference between investments in 1996-1998 and 2001-2003					
	Fixed effect panel			Fixed effect panel matching to sample		
Innovated product in 2000	0.10 (2.14)	0.12 (2.43)	0.12 (2.39)	0.14 (2.09)	0.14 (2.08)	0.13 (1.86)
Year	-0.31 (10.09)	-0.31 (10.21)	-0.46 (7.74)	-0.34 (7.00)	-0.34 (7.03)	-0.47 (5.30)
Sector	-	Yes	Yes	-	Yes	Yes
Controls	-	-	Yes	-	-	Yes
N	9,308	9,308	9,298	4,035	4,035	4,028
R^2	0.03	0.04	0.05	0.03	0.05	0.06

t-statistic in parentheses. Controls: average schooling of labor force, scale of firm, age of firm and location.

Table 10 – Difference-in-difference equation: process innovation

Independent variable	Dependent variable: Difference between investments in 1996-1998 and 2001-2003					
	Fixed effect panel			Fixed effect panel matching to sample		
Innovated process in 2000	0.16 (3.48)	0.17 (3.58)	0.16 (3.34)	0.18 (2.62)	0.17 (2.44)	0.15 (2.16)
Year	-0.35 (10.38)	-0.35 (10.39)	-0.49 (8.11)	-0.37 (7.09)	-0.37 (6.99)	-0.49 (5.41)
Sector	-	Yes	Yes	-	Yes	Yes
Controls	-	-	Yes	-	-	Yes
N	9,308	9,308	9,298	4,035	4,035	4,028
R^2	0.03	0.04	0.05	0.03	0.05	0.06

t-statistic in parentheses. Controls: average schooling of labor force, scale of firm, age of firm, location.

These findings uphold the causality hypothesis, revealing that the firms that innovated products invested roughly 10% to 12% more in fixed capital than the firms in the control group. The corresponding figures for process innovations lie in the 16% to 17% range. In the case of the fixed effect panel matching to sample, firms that innovated products invested 13% to 14% more in fixed capital, while those that innovated processes invested between 15% and 18% more than those in the control group.

5 Conclusions

In this article, strong evidence has been found in support of the hypothesis that investment in *R&D* raises investment in fixed capital, thereby accelerating the growth of firms in Brazil. The study was based on data referring to the 23,892 manufacturing firms which, taken together, accounted for 95% of the total industrial value added of Brazil in the period 1996-2003. Various statistical approaches were employed, as outlined in the following chart on the procedures adopted and results obtained in this study.

With a view to providing solid proof of the hypothesis that a causal relation exists between investment in *R&D* and investment in fixed capital among firms in Brazil, the statistical procedures were developed according to a three-step sequence.

In the first step, descriptive statistics revealed that, in the period 1996-2003, firms that invested in *R&D* also invested more in fixed capital. This procedure was adopted as a means of presenting and describing the main indicators used in the study.

The second step was aimed at establishing a statistical correlation between investments in *R&D* and investments in fixed capital, as well as at correcting for selection bias or problems related to endogenous variables. To this end, an OLS model was first estimated for regressing investment per worker and the investment/net sales revenue ratio as functions of the innovative status of the firm and of the R&D investment of the firm. To correct for selection bias, a two-stage model relating *R&D*, innovation and fixed investment was estimated.

A five-equation system was then estimated and innovation and fixed investment were related through an equation framework similar to that developed by Crépon, Duguet and Mairesse (1998). For specifying the model, another reference was the model developed by Lach and Rob (1996), who suggest that when ideas become innovations, they need to be implemented via new machinery and equipment, which leads to additional investments in fixed capital. Different from the CDM models, in the equation system estimated, a firm-growth equation was used instead of the productivity equation and a survival equation was introduced to correct for selection bias. The hypothesis adopted for the error correlation structure, which follows Lööf and Heshmati (2002), lies between that proposed by Griliches (1979) and the CDM models.

In the third step, the causal relation between investment in *R&D* and investment in fixed capital was further explored using two procedures. First, a quasi-natural experiment grouped the firms in clusters according to their major characteristics. By accompanying these firms over time, it was possible to identify those that had invested in *R&D* within each cluster and then verify which of these had invested most in fixed capital. Then, a difference model was estimated, together with another model in which difference-in-difference estimates were combined with propensity score matching.

To finalize, having corrected for selection and endogenous variable biases and verified the existence of a causal relation between *R&D* and investment, the results of the analyses can be said to support the hypothesis proposed since they reveal that Brazilian firms that invested in *R&D* also invested an average 17% more in fixed capital than those that did not. Whereas the growth rate of the stock of fixed capital was correlated with the initial stock among smaller firms, it was random among larger firms, thus confirming the weak version of Gilbrat´s law as developed by Simon and Bonini (1958). The results obtained also confirm the Jovanovic (1982) learning hypothesis.

Chart 1 – Summary of procedures and results

Method	Potential	Independent variable	Dependent variable	Estimated increase in fixed investment in relation to average
Descriptive statistics	Describe data	Firms that always invest in *R&D*	Fixed investment per worker	57.74%
Descriptive statistics	Describe data	Firms that always invest in *R&D*	Fixed investment/net revenue	14.28%
OLS	Estimate correlations	Innovative firms	Fixed investment per worker	31%
OLS	Estimate correlations	Innovative firms	Fixed investment/net revenue	24%
OLS	Estimate correlations	Firms that always invest in *R&D*	Fixed investment per worker	9%
OLS	Estimate correlations	Firms that always invest in *R&D*	Fixed investment/net revenue	13%
2-stage: probit and OLS	Correct for selection bias	Estimated probability of firm innovating/*R&D*	Fixed investment per worker	15.5%
2-stage: probit and OLS	Correct for selection bias	Estimated probability of firm innovating/*R&D*	Fixed investment/net revenue	10.8%
3SLS	Correct for selection and endogenous variable biases	Product innovation/*R&D*	Growth rate of stock of fixed capital	17% for all firms 13% for small firms 19% for large firms
FIML	Correct for selection and endogenous variable biases	Product innovation/*R&D*	Growth rate of stock of fixed capital	19% for all firms 14% for small firms 24% for large firms
3SLS	Correct for selection and endogenous variable biases	Process innovation/*R&D*	Growth rate of stock of fixed capital	17% for all firms 13% for small firms 19% for large firms
FIML	Correct for selection and endogenous variable biases	Process innovation/*R&D*	Growth rate of stock of fixed capital	17% for all firms 21% for small firms 21% for large firms
Cluster with difference – difference	Define direction of causality	Firms that always invest in *R&D*	Fixed investment	+
Cluster with difference – difference	Define direction of causality	Firms that always invest in *R&D*	Fixed investment/net revenue	+
Difference model	Define causality	Product innovation	Difference in fixed investment	12%
Difference model with PSM	Define causality	Product innovation	Difference in fixed investment	13%
Difference model	Define causality	Process innovation	Difference in fixed investment	16%
Difference model with PSM	Define causality	Process innovation	Difference in fixed investment	15%

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