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Productivity differences in Brazilian manufacturing firms, by industrial sector

Ronivaldo Steingraber and Flávio Gonçalves

This article attempts to explain how the innovation process is determined by factors external to the firm, whose productivity is calculated and analysed in terms of systemic innovation factors. To that end, it describes the internal innovation capabilities of firms, which explain variations in their productivity across sectors. The productivity of manufacturing firms is constructed using the Abramovitz residual method (social accounting), referred to as total factor productivity (TFP), or the Solow residual. Nonetheless, a number of theoretical problems are avoided, such as the effect of scale, aggregation and the heterogeneity of the factors considered in the model. The TFP of Brazilian manufacturing firms is explained by their internal capabilities and by product innovation in the sector to which they belong, which shows that innovation depends on institutions located within the industry.

Ronivaldo Steingraber
PhD in Development Economics
Federal University of Santa Catarina
ronivaldo.steingraber@gmail.com

Flávio Gonçalves
Professor, Postgraduate Course in Development Economics
Federal University of Paraná
f.goncalves@ufpr.br

I
Introduction

Economic growth has broad synergy with productivity growth in firms and the innovation process. Productivity and innovation are closely related, with two-way causality: a productivity increase leads to innovations being introduced in firms, and the innovation process leads to productivity growth.

This study attempts to explain how the innovation process is affected by factors external to the firm. Enterprise productivity is calculated and analysed in terms of systemic innovation factors, for which the firms' internal capabilities for innovation are identified. These capabilities cause differences in enterprise productivity across sectors. Separating the analysis into different sectors reflects the notion that firms have varying productivity levels —partly stemming from sectoral differences in institutions and the formation of social capital, but also from the structure of the industry itself. Product innovation by sector was adopted as a systemic factor of innovation (broadly defined) in the empirical model. This type of process depends on interaction between the firm and external agents or institutions —typically the government and universities, among others— and interaction with other firms (competitors, suppliers, distributors, or specialized service providers, consulting firms, and so forth). This interaction is referred to as social capital and is an important step towards promoting the innovation process in the economy.

The productivity of manufacturing firms is constructed using the Abramovitz residual method (social accounting). This is referred to as total factor productivity (TFP), or the Solow residual; but the analysis is conducted in a way that avoids several theoretical problems raised by the critique made by the Schumpeterian literature, such the effect of scale, aggregation and the heterogeneity of the factors considered in the TFP calculation.

A multilevel regression model is used to explain TFP in terms of the internal capabilities of firms in relation to the innovation process, the sectoral characteristics of Brazilian industry, and the presence of product innovation in industrial sectors. This approach makes it possible to analyse intra-group effects in the observations studied, which represent sector productivity differences and the repercussions of product innovation by industrial sectors on productivity at the firm level.

Product innovation was chosen because of the need to identify the effect of institutional variables on the process of innovation and productivity growth among firms in Brazilian industry. The analysis was based on data from the Survey of Technological Innovation (PINTEC)[1] for 2005. Innovation can be viewed in three categories: products, processes or organization.[2]

This article is organized in six sections apart from this introduction. Section II analyses the internal capabilities of the innovation and productivity-growth process in firms. Using the Hall and Mairesse (2006) model, innovation and productivity gains are found to be the initial sources of the systemic innovation process. The analysis of productivity is more wide ranging, since not all Brazilian manufacturing firms were innovators in 2005, according to PINTEC data. Using productivity makes it possible to compare firms included in the database of the Brazilian Geographical and Statistical Institute. With a more general model, the role of capabilities, institutions and the sector in enterprise productivity can be identified more easily.

Section III reviews the debate over the existence of productivity differences between firms even within the same industrial sector. Institutional and sectoral differences are highlighted in keeping with the Schumpeterian systemic innovation literature.[3] The sectoral approach of the analysis is justified by the research done in recent years, which has had an exclusively micro - or macroeconomic focus. This exercise aims to make a sectoral (meso-economic) contribution to analyse the innovation process in Brazilian industry, based on microeconomic capabilities for innovation, as a function of the institutions involved in product innovation in the macroeconomic environment of Brazilian manufacturing industry.

Section IV identifies total factor productivity, which, as noted above, is calculated through the Abramovitz residual. Critiques of the use of TFP in the heterodox literature are also commented on in this section.

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[1] Research on Technological Innovation of the IBGE. Total factor productivity is calculated using data from the Annual Industrial Survey (PIA); enterprise capabilities are identified through various variables obtained from the IBGE database.

[2] The empirical research was done through a research project undertaken with the IPEA, for the use of IBGE micro data. The work was restricted to the available resources. In the future, other research projects could analyse the subject in greater depth, considering other forms of innovation or interaction with the environment.

[3] Innovation systems are as follows: the National Innovation System (SNI), the Sectoral Innovation System (SSI), the Regional Innovation System (SRI) and the Technological System (ST).

Section V analyses the multilevel model on two levels, capturing the differences between sectors in enterprise TFP. Total factor productivity is also analysed at the first level as a deviation from the sector average resulting from the firm's innovation capabilities. At the second level, TFP is analysed as a sector average based on the deviation from the general average of Brazilian industry and the impact of institutions, captured by the average of product innovation.

Section VI describes and discusses the results obtained. These confirm the hypothesis that the innovation process is systemic, since meso-economic factors (from industry) as well as institutional ones and social capital, influence TFP through the innovation capabilities possessed by the Brazilian manufacturing firms analysed. Section VII, setting out the conclusions, identifies the Brazilian industrial sectors that are most sensitive to the systemic innovation process through sector control and product innovation in the sector. Nearly one third of Brazilian industrial sectors display productivity differences above and below the industry average related to the product-innovation process.

II
Enterprise innovation capacity

The study by Solow (1956) helped to establish the crucial role of technical progress in the economic growth process. This seminal contribution, based on a macroeconomic approach using a Cobb-Douglas-type production function, opened up a vast field of theoretical and empirical research in neoclassical economics. This line of research has no microfoundations, however, and it assumes exogenous technology and the introduction of innovations based on the calculation of TFP. Nonetheless, following the pioneering work of Nelson and Winter (1982), the study of economic growth driven by technological progress has made progress in incorporating microfoundations.

In Nelson and Winter (1982) the firm allocates time and resources for the purpose of learning new modes of production, incorporating technical knowledge into its operational routines (production, planning, marketing, among others). These authors analyse the routine of the firms, which they define as the way skills are processed, and the behaviour and organizational structure of the firm, which are strongly path dependent in relation to accumulated resources. The firm's learning is linked to its routine and accumulated capabilities, which will determine its innovation capacity in the future.

In the Schumpeterian literature, the microeconomic emphasis in the innovation process can be seen in the firm's set of skills and capabilities devoted to the generation, absorption and the use of technical know-how, which allow innovations to take place.[4]

[4] The concept of *"capability"* is defined in the seminal article by Teece, Pisano and Shuen (1997), which analyses the formation and importance of capabilities in firms.

According to Vakratsas and Ma (2009) a firm's innovation capabilities are multifaceted, because they possess several components that can be divided into three groups: capabilities for innovation, capabilities for absorption and capabilities for adaptation. In general, capabilities for innovation focus on the creation of new technological knowledge, and their economic application in the form of new products or services. Absorption capabilities concern interaction with elements outside the firm, which incorporate the new forms of knowledge presented in society; absorption in this sense is nothing more than what is learnt by the firm in terms of knowledge that is new (for the firm or for the market). Lastly, adaptation capabilities show that the firm's organizational structure needs to be adapted in response to new knowledge developed or absorbed by the firm.

The approach adopted by Vakratsas and Ma (2009) envisages technological knowledge that can be transformed into innovations. The author justifies focusing on knowledge, rather than just innovation, owing to the development of specific capabilities in the firm that fulfil different functions, often preceding the innovation process, or occurring afterwards.

Thus, the review of microeconomic factors, such as capital (through investment) or human capital, do not make it possible to define the knowledge profile adopted by the firm, or how innovation is developed and contacts and networks established with institutions for the development, absorption and use of knowledge. More information is needed to identify the strategic focus adopted by the firm and its organizational routines. Mulder and others (2001) also consider decision-making rules in addition to enterprise routine and the organization of capabilities in relation to the innovation process, which means that firms with similar capabilities could have a different innovation strategies and outcomes, based on their different internal strategy and organizational rules.

According to the dynamic of the innovating firm presented by Hall and Mairesse (2006), the firm has various capabilities for innovating and generating productivity gains; these capabilities precede innovation itself, are factors of knowledge accumulation and are present in the marketing stages of the innovative product.

In general, the analysis of innovation based on enterprise capabilities only shows the microeconomic side of the process, while ignoring the firm's relationship with the institutional environment and the sector constraints imposed on the firms.

Another important point is the influence of the industry on the innovation dynamic. The industry has its own concentration which determines firm size. The size of the firm determines its capacity for investment in research and development, and the exploitation of economic opportunities for innovation (such as investments in the marketing of new products). In general, larger firms can distribute the fixed costs more effectively and deal better with innovation risk compared to smaller firms.

According to Dosi (1982) and Antonelli (1999), the industry also follows a specific technological path. The central idea is that the technological path (the generation, application and use of scientific knowledge) is concentrated at the industry level. This knowledge can spill over into other industrial sectors to generate new opportunities, as noted by Mowery and Rosenberg (2005); but the initial focus of the new technology and its development are present in the industry.

The firm's knowledge and how innovations are incorporated cannot be identified merely by analysing the innovative product or patents generated. For Hall and Mairesse (2006) this knowledge comes from investments in innovation and expenditure on research and development (R&D). Nonetheless, these investments can be absorbed from other enterprises and industries, forming a spillover effect. Other institutional actors that generate technological knowledge and innovations, such as universities and research centres, are equally important in the innovation process but not counted in the firm's R&D expenditure.

Antonelli (1999) shows that the institutional environment is oriented towards the development of innovations through the formation of a structure for supplying innovation services. These services are absorbed by the firms through channels and networks of relations with other actors, whether economic (such as other firms) or social (such as universities).

Analysis of the innovation process should take account of its systemic elements, such as the institutional environment for innovation, which includes the formation of social capital (social relations) between the firm and institutional actors and with other firms, the economic structure of the industry, and geographic limits involving other economic and institutional actors. On the geographical impact of innovation, Dosi, Llerena and Labini (2006) show that the technological knowledge incorporated in organizations and individuals is geographically concentrated. This limits the absorption of knowledge and the development of innovations, because greater distance means less knowledge absorption by more individuals and firms.

To capture the internal and external capabilities of the innovating firm, a multilevel regression model was used, which will be presented in section IV. Next, the theoretical reasons why firms have productivity differences are discussed. This fundamental hypothesis is premised on the notion of heterogeneity among the economic and social actors involved in the innovation process; otherwise, technological convergence would ensure equal micro- and meso-economic performance for all firms and industries, thereby obviating the need to analyse the systemic characteristics of innovation which would tend towards an average value in the economy.

III

Why do firms have different productivity levels?

The analysis of firms' innovation capabilities shows how these depend on interaction with the external environment, forming a systemic innovation process that involves institutions and social capital, in addition to the meso-economic conditions of the industry itself, such as the technological path. There is also an interdependent relationship between innovation and productivity, as identified by the Hall and Mairesse (2006) model. Innovation capabilities show the importance of innovation in the firm and its productivity, and depend on external factors, as Kelley and Helper (1999) and Encaoua and others (2000) who highlight in their studies.

Thus, the identification of innovation or the productivity of the firm must be related to the institutional development, social capital, and structural characteristics of the industry. This requires more in-depth analysis of productivity models;[5] and their critiques and applicability should be extended to the concept of systemic innovation.

Traditionally, productivity is analysed using a Cobb-Douglas- type production function to explain economic growth, following the Solow model.[6] That model has two limiting factors in its definition of productivity based on technical progress. The first is aggregation, because the model was designed to explain macroeconomic growth (of countries rather than firms), so it lacks a microeconomic foundation. In the Schumpeterian literature, the microeconomic foundations are different from neoclassical assumptions. The aggregate production function thus has to incorporate the different sector (industry) and enterprise production functions. This breakdown cannot assume the same conditions as the macroeconomic model, because the firm in the Schumpeterian literature has its own capabilities for innovation, apart from depending on institutions and the formation of social capital.

The second limiting factor in Solow's aggregate model is the assumption of constant returns to scale. While this can be assumed in relation to the macroeconomic study, in a study of the impact of technological change and innovations on the productivity of the industry and firms, constant returns to scale contradicts one of the main characteristics of innovation namely increasing returns to the application of knowledge in the innovation process. Increasing returns to scale in the application of knowledge generates productivity differences between firms. In the Schumpeterian literature these differences form the principle of heterogeneity among economic agents, both between firms and between industries. Heterogeneity can also be explained by institutional differences and the formation of social capital; in other words, not only may institutions differ between economic sectors, but —within the same sector— the same institution forms different arrangements and connections with firms, which thus produce different results and impacts in terms of productivity and firms' capacity to innovate.

Antonelli (1999) argues that the heterogeneity present in the innovation process is a function of the organization of knowledge, which can be embodied in four different organizational-structural processes, defined as: (i) entrepreneurship; (ii) institutional variety; (iii) vertical integration; and (iv) technological cooperation.

The way knowledge occurs, according to the four classifications of Antonelli (1999), shows interdependence in the construction of a "social contract" between firms and institutions, which is the definition of social capital.[7]

Bottazzi and others (2001) analyse the evolution of technology and innovations in the pharmaceutical industry, concluding that heterogeneity tends to persist because firms differ in their propensities to innovate, since new markets are created through innovations. Logically, the capacity for new markets to open in response to the innovation process differs from industry to industry.

Dosi (2006) shows that the differences between industries are explained by more than merely the trend

[5] The choice of productivity as the analytical variable to be explained is justified for two reasons. The first is historical; the economic literature has traditionally focused more on the study of productivity. Secondly, information on innovation is generally in the form of dummy variables, of the type "innovated" or "did not innovate". It was decided to analyse productivity (of all firms) and to explain this in terms of systemic capabilities for innovation and other characteristics of the firm, sector and institutional environment. Clearly, the inverse relation is also valid: innovation can also be explained by productivity.

[6] See Romer (2001) for an analysis of the different growth models in the economics literature.

[7] See Putnam (2001), Coleman (1988) and Knack and Keefer (1997) for the definition of social capital, and Nelson and Sampat (2001) for the importance of social capital in the process of innovation in the economy.

of demand.[8] For this author, heterogeneity among firms and industries is explained by different perceptions and capacity to exploit economic opportunities relating to innovation. These opportunities, in the first analysis, depend on the characteristics of the firm; the firm accumulates knowledge, but depends on its own characteristics and on the economic and social environments that permeate the generation, dissemination and use of technology.

The modernization of the firm's technology depends on the evolution of its path within the technological paradigms to which it belongs. Dosi (1982 and 2006) show that the technology path can be analysed in an industry on the basis of the specific characteristics of the structure and institutions present in the industry, which determine the evolution of technology. The interaction between the characteristics of the industry and institutions forms social capital, which depends on geographic factors related to industrial concentration and defines the pace of evolution of the technological paths.

In relation to the role of geographic concentration in the innovation process in the industry, Audretsch and Dohse (2007) envisage the problem of the search for innovation in the firm as depending on the characteristics of the industry and its location. The presence of institutions and the formation of social capital become territorially specific, depending on the industries present and the level of agglomeration of the firms in question. The authors suggest that the combination of these factors favours the development of additional knowledge that will culminate in more innovations.

Knowledge becomes a social function, and the firm, given its geographic and economic limits, has to interact with actors that are involved in the development and dissemination of knowledge. Although the absorption of this knowledge depends on the characteristics of the firm, the role of the actors involved in the process is also important. Audretsch, Lehmann and Warning (2005) show how the relation between the economic and social environment models the innovation process in defining the concept of technological entrepreneurship. For these authors, technological entrepreneurship depends on the construction of a knowledge network focused on the promotion of new businesses based on knowledge application, supported by the university and mainly involving small firms. This entrepreneurial spirit depends on the knowledge cycle in the industry. Mature industries, dominated by large firms, do not form social capital promoting entrepreneurship. New technologies open up economic opportunities for technological innovation; but the exploitation of these opportunities depends on the network established between university and the small firms.

Sector differences in the innovation process are explored in the study by Klevorick and others (1995), who analyse the differences in R&D between industries, and define three explanatory factors. The first stems from market structure and firm size, which is considered a weak and easily refutable argument. The second factor is market size and the growth of demand. The third factor is the extent to which scientific knowledge can be appropriated, which depends on: (i) the progress of scientific knowledge; (ii) progress arising from outside of the industry; and (iii) feedback of the technology.

The factors highlighted by Klevorick and others (1995) depend directly on the organizational structure of the firm in the innovation process, because the way the firm relates with the environment is what determines its learning capacity for innovation. Lam (2004) highlights the role of organizational innovation in the firm's innovation process and views organizational innovation as a pre-requisite for technological innovation related to endogenous factors in the firm, such as values, learning capacity, interests and the power of change for technological adaptations. Nonetheless, the mere presence of organizational innovations does not ensure that the firm can develop innovative products or processes; but it is a necessary but insufficient condition for innovation in the firm. Organizational innovation shows that the firm needs a format for communicating with institutions and forming the social capital needed to absorb technological knowledge and the development of innovations.

Lastly, Martin and Scott (2000) discuss the role of public support for innovation. The government encourages the formation of relevant research in universities through its public policies; it promotes information exchange between industry and academia; it supports marketing and commercialization processes; it links professionals in the technology domain, and it promotes technological dissemination.[9] Nelson (2006) presents the firm as an organization that needs to develop capabilities to establish communication channels and knowledge capture with institutions. The observed outcome reflects differences in access to technology between the firms.

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[8] Demand plays a role in the definition of innovations, but it is not the only explanation. The consumer is an information source in the innovation process, but other sources, such as distributors, suppliers and institutions are also important. See Dosi (2006) for a critique of the evolutionary model of demand-pull innovations.

[9] The government's role in innovation processes can be analysed in the studies by Kim (2005).

Nelson (2006) insists that the firm's productivity does not depend solely on the volume of factors used, but also on its internal capabilities and the institutional environment in which it operates, which varies between industrial sectors.

In other words, firms are seen as organizations with their own characteristics that generate tools for interacting with the environment to absorb knowledge and develop innovations in their organizational routines. The change caused by the introduction of an innovation depends on organizational changes (innovations). The heterogeneity of firms stems from their own decisions on the innovation strategy. In this way, the analysis of the firm's characteristics is complex, because consideration needs to be given to how social capital is formed (scope and durability of co-operation partnerships) with institutions and other important actors in the innovation process.

Systemic innovation is investigated on two levels here. The first level is the firm, seen as an organization that communicates with the external environment, with the aim of absorbing technological knowledge to innovate.[10] The second level involves the industry, viewed as a system combining various actors involved in evolution of the technology used, and the availability of the structure (location, concentration, among other factors), institutions and social capital present in each type of industry.

An economic model for empirical analysis of the innovation process will be presented in the next section.

[10] This point also shows that microeconomic research into the innovation process in Schumpeterian theory is broad and complex. Analysis merely of the factors of production used ignores the internal effort needed for a firm to succeed in innovating, which involves its relation with the external environment.

IV

Modelling inter-sector productivity differences

Although TFP is traditionally calculated as the Solow residual, this does not explain the presence of internal factors (capabilities) and external ones (institutions and industry characteristics), which the Schumpeterian literature considers decisive for innovations and productivity gains. According to Nelson (2006), while these effects can be considered exogenous, they are known to be important and form part of the structure of the innovation process, directly and systematically affecting enterprise productivity. Thus, external elements relating to sector characteristics (of the industry), the location of the firm and its relation with institutions, need to be included in the analysis of the firm's productivity.

Calculating TFP as a way to analyse the technological progress of the economy is also criticized in non-orthodox theories. Felipe and McCombie (2007) argue that the TFP calculation is tautological and does not explain the existence of growth differences (in this case between countries).

The critique of the use of TFP as a determinant of aggregate technological progress is mitigated by using sector data. The study by the Organization for Economic Cooperation and Development (OECD, 2001) moves in this direction and shows the sector contribution of productivity rather than calculating aggregate TFP for the economy as a whole.

In that regard, the more disaggregated the TFP calculation is, the more consistent is the result, since the factors measured are more homogeneous and allow for more precise comparisons. The sector analysis avoids the mistake of measuring an average economy-wide productivity that does not reflect the microeconomic heterogeneity of the factors used in economic activity.

The use of microdata in econometric models allows for even greater progress. Total factor productivity can be calculated by firm, aggregated by sector (or subsectors) of the economy, according to the level of homogeneity desired in the study.

The major problem in using TFP, as shown in the critique by Felipe and McCombie (2007), is the tautology present in the (neoclassical) model. The calculation of TFP does not explain its origin, which stems from efficiency gains in economic activity or from increased factor use. Hulten (2000) discusses the importance and shortcomings of analysing productivity through the Solow residual, and concludes that merely calculating TFP is not sufficient, since it needs to be explained in terms of the characteristics that determine the firm's productivity.

Although productivity differences between firms need to be identified and explained by their capabilities, they also reflect differences between industries.

The relation between the firm's productivity and its external characteristics is captured by the multilevel regression model, in which grouping factors explain its independent variables. The grouping used is specifically the economic sector or industry, according to the National Classification of Economic Activities (CNAE 1.0).[11]

Before estimating the model itself, the nonexistence of the productivity variable (including TFP) in the database used was verified. Thus, the first step in the empirical model presented here is to develop a productivity estimate. The TFP estimation has various empirical alternatives in the economic literature, but the Abramovitz residual (1956)[12] was chosen in this case, as suggested by Antonelli (2003).

The Abramovitz residual can be determined as follows:

$$TFP = dY - \left(\frac{dy}{dk}\right)dK - \left(\frac{dy}{dl}\right)dL \qquad (1)$$

where dY is the variation in output. The derivatives $\left(\frac{dy}{dk}\right)$ and $\left(\frac{dy}{dl}\right)$ represent elasticities of output with respect to capital and labour, respectively; and dK and dL are the variation in capital (investment) and labour in relation to output.

The advantage of using the TFP estimate in (1) consists of the relation between investment as a factor explaining the variation of capital with respect to output, since the industrial production statistic contained in the Annual Industrial Survey (PIA) does not give a specific value for capital. Another advantage is the fact that the elasticities of factors with respect to output do not measure their marginal contribution but their relative share.

As the productivity calculated in (1) is a differential, it reflects the variation of the factors used from one year to another. This characteristic makes it possible to determine the origin of productivity through variables specific to the firm, along with the sector and institutional variables present in the initial year. As the variables related to explaining innovation and the institutions needed for technical progress are included in the PINTEC study, with three data series (2000, 2003 and 2005), TFP can be calculated in these years as a function of its respective previous years. The year 2005 was chosen as the focus of this study since it is the last year available. Future research could extend the analysis to other years.

[11] National Classification Economic Activities maintained by the IBGE.

[12] Despite similarity with the Solow model, Abramovitz (1956) uses social accounting to define the portion of output that is not explained by factors of production. He does not discuss the form of the production function or its type of returns. The TFP estimate developed in this paper introduces the scale variable (contracts) to specify a production function with increasing returns to scale.

V

Estimating TFP using the multilevel regression model

According to Hsiao (2003), the multilevel regression model can deal with the problems of cross-section estimates that make the parameters indeterminate, when analysing individual or inter-temporal differences. According to this author, another solution would be to introduce dummy variables to capture these differences. Nonetheless, the use of dummy variables does not deal with the problem in estimating the model if there are differences between the population groupings studied, and it does not explain differences between groups in terms of individual behaviour.

These are the specific advantages of using the multilevel model: to determine the differences between groups and the sensitivity of these differences in the behaviour of the individuals in the different groupings. In other words, if the elasticities between the groups are different, the multilevel model can provide good estimates of these differences and their inter-relationships in the population studied.

Raudenbush and Bryk (2002) describe the two-level multilevel model used in this article, while Hsiao (2003) presents a three-level multilevel model. The difference is in the capacity of the third level to capture the evolution of the groups through time. Use of the three-level model is compromised by the fact that data are only available for three years, which does not form a consistent time series.

The two-level multilevel model starts by determining the fixed effects at the first level. The statistically significant parameters in the first level are then explained in the second level.

The first level consists of the dependent variable, total factor productivity (TFP_{ij}), where i represents firm ($i = 1, 2, 3 \ldots n_j$) and j the industry sector to which the firm i belongs ($j = 1, 2, 3 \ldots J$). The dependent variable can be explained as a function of a fixed effect (β_{0j}) and a random effect (r_{ij}), defined as:

$$TFP_{ij} = \beta_{0j} + r_{ij} \tag{2}$$

The fixed effect (β_{0j}) captures the average of sector j to which firm i belongs. The random effect (r_{ij}) captures the effects outside the control sector j, in other words, the general average of all industry sectors analysed (J), which corresponds to the average of Brazilian industry and is defined as:

$$\beta_{0j} = \alpha_0 + \sum_{i=1}^{S} \alpha_s Z_{sj} + \tau_j \tag{3}$$

where $\sum_{i=1}^{S} \alpha_s Z_{sj}$ is the set of s external variables, belonging to the grouping (industry), which explains the average TFP of the industry in (2).

The variables are used are centred on the mean, which shows that the variables of the first and second levels explain deviations of productivity from the average of the sector and Brazilian industry, respectively.

Equations (2) and (3) show that using ordinary least squares (OLS) is inefficient owing to the unequal distribution of observations between the groups. Nonetheless, apart from generalized least squares, the model can be estimated using the maximum-likelihood method.

The variables chosen to estimate the model at the first level are:

$$\overline{TFP}_{ijt} = \beta_1 + \beta_2 \mathbf{L}_{ijt} + \beta_3 \mathbf{I}_{ijt} + \beta_4 \mathbf{PeD}_{ijt} + \beta_5 \mathbf{E}_{ijt} + \beta_6 \mathbf{CE}_{ijt} + \xi_{ijt} \tag{4}$$

where $\overline{TFP}_{ijt}$ is the centred total factor productivity of firm i in sector j. **L** is a vector containing the firm's human capital characteristics, **I** is a vector of the firm's physical capital investment, **PeD** is a vector of research and development variables, **E** is a vector containing scale variables,[13] and **CE** is a vector representing the firm's external trade. Equation (4) also contains a linear coefficient (α_1) that captures the effect of sector and macroeconomic variables on the firm's productivity, and the random error ξ_{ijt}.

The variables used are defined in Annex A, and the results are presented in the next section. The complete model and discussion of the methodology are discussed in Steingraber (2009).

[13] The scale variables introduced into the model aim to alleviate the theoretical problem of assuming constant returns to scale in the TFP estimation.

VI
Results

The results obtained in the estimation of (4) are shown in table 1 below.

The independent term, which is significant and positive, is the sector average TFP, which means that the sectors have a positive impact on the productivity of the firms (as an *animal spirit* effect).[14] The non-significant results are interpreted as not differing from the sector average; the significant results represent the deviations in the TFP of firms in their sector, and can be either positive (the TFP of the firms considered is above the average TFP of the industry) or negative (the TFP of the firms considered is below the industry average TFP).

[14] A concept used by Keynes to describe the emotions or feelings that influence human behaviour, which can be measured in terms of consumer confidence.

TABLE 1

Results of the estimation of first-level fixed effects

Variable	Estimation	Standard deviation	t-statistic	Probability ρ
Intercept	4 374 488	845 294	5.18	<.0001
Percentage of the labour force with tertiary education	-63 163	11 488	-5.50	<.0001
Average income	-4 199.43	1 333.66	-3.15	0.0016
Average time of employment	-83 276	36 689	-2.27	0.0232
Average schooling	1 517 495	720 916	2.10	0.0353
Average experience	576 563	273 520	2.11	0.0351
Innovating labour force	1 104 337	35 880	30.78	<.0001
Number of patent applications	1 221 765	81 187	15.05	<.0001
Share of employment[a]	$-1.09*10^{11}$	57 253 332	-1.90	0.0575
Share of income[b]	$-7.18*10^{11}$	45 752 467	-15.70	<.0001
Contracts	9 112.79	1 528.66	5.96	<.0001
Value exported	-0.00395	0.01850	-0.21	0.8309
Value imported	13 797	0.03175	43.45	<.0001
Percentage of international inputs	-336 793	52 556	-6.41	<.0001
Capital turnover	20 881	186 859	0.11	0.9110

Source: Prepared by the authors on the basis of data from the Brazilian Geographical and Statistical Institute (IBGE).

[a] Firms's share in total sector employment.
[b] Firms's share in total sector capital income.

The values calculated show that value exported[15] and capital turnover are not significant. In other words, these variables affect the TFP of firms (negatively and positively, respectively) in a similar way to the sector average, so they do not explain differences in firms' TFP above or below the average TFP of the sector.

The variables reporting a negative sign were: the percentage of the labour force with tertiary education, average income, and the average time for which the worker has been employed in the firm, the firm's market share,[16] and the percentage of imported inputs. These variables help explain the TFP of firms in each sector of Brazilian industry, but their contribution is below the average of sector *j* to which firm *i* belongs (measured in the independent term).

The negative result in the TFP impact of these variables can be explained by differences between and within sectors. The inter-sectoral difference stems from the smaller impact of these variables on the industry-average TFP, taking account of the impact of the other variables of the model. The intra-sector difference stems from the smaller impact of these variables on sector TFP compared to the impact of other variables on the average TFP of the sector in question. While the difference between sectors points to the impact of macroeconomic variables that are not yet explicit in the model, the intra-sector difference reflects productivity differences between firms in the same sector based on meso-economic characteristics. The origin of productivity differences between firms in relation to innovation capabilities are thus explained by factors external to the firm, and pertain to the meso-economic and institutional environment relevant for the innovation process and productivity gains.

The significant variables that have a positive impact on the TFP of firms by sector are: schooling, work experience (in the sector), the presence of innovative labour, patents, firm size and imports. This group of variables had an influence on the formation of above-sector-average productivity gains at the firm level.

The mere search for human capital does not increase firms' TFP or introduce human capital for innovation. The search for innovative labour —rather than just more labour with higher education, higher income and more experience in the firm— is what has the greatest impact on the firm's productivity. Firms that import more (in total value terms) obtain productivity gains over and above what is explained by the additional imported inputs per se. This means that the imports also embody technological factors because inputs will be purchased where they cost least.

[15] In relation to the non-significant result for value exported, the negative sign shows that the impact on productivity is below the sector average for Brazilian manufacturing firms. Araújo (2006) shows that industrial enterprises display *ex ante* productivity gains (related to innovation) and then increase exports. The economics literature (see Greenaway and Kneller (2007)) refers to this effect as "learning by exporting" and confirms the hypothesis that productivity gains fade as exports grow through time.

[16] In this article, as indicated in table 1, the firm's market share is calculated through two variables: (1) the share of total employment in the sector and (2) total sector income. For a more detailed definition of the variables used in the estimatd models in this article see annex.

The weak influence that human capital has on enterprise productivity is consistent with the results obtained by Landesmann and Stehrer (2007). These authors show that in Latin America, the distribution of workers' pay following the introduction of innovations is not convergent between high- and low-technology sectors, according to results obtained in developed and East Asian countries. Thus, the negative relation found between productivity and human capital formation (generation of employment in the firm, more workers with higher education, higher income) shows that, on average, many firms obtain low returns from the introduction of innovations and human capital improvements. In other words, there are microeconomic differences between firms in their capabilities for innovation, apart from productivity gains.

In relation to experience, time employed in the firm generates less productivity gains than time employed in the sector (in other firms). This result shows that firms tend to seek skilled labour in the market rather than invest in training for their workers. This reflects a lack of institutions to protect firms from opportunistic appropriation of their human capital investments.

The second-level equation (3) considered in the estimation explores how external productivity gains (in the sector) reflect product innovation in the sector. This in turn depends on the presence of institutions, such as the government, universities, in addition to interaction between the innovative firm and other firms, suppliers, distributors, etc. The equation to be estimated at the second level is:

$$\beta_{.j} = \beta_0 + \beta_1 Ino\ prod + e_j \qquad (5)$$

where β_{0ij} is the linear coefficient estimated in (2), and *Ino prod* is product innovation. Substituting equation (5) in (2) gives the two-level multilevel regression in a single equation, expressed as:

$$\underbrace{TFP_{ijt}}_{TFP\ of\ the\ firm} = \underbrace{\beta_0}_{Average\ TFP\ of\ the\ sector} + \underbrace{\beta_0 X_{sijt}}_{Fixed\ effect\ of\ the\ firm} + \underbrace{\beta_1 Ino\ prod_{sjt} + \beta_2 Ino\ prod_{sjt} X_{sijt} +}_{Fixed\ effect\ of\ the\ sector} + \underbrace{e_{jt} X_{sijt}}_{Random\ effects} + \underbrace{r_{.j}}_{Total\ error} \qquad (6)$$

In general, equation (6) can be divided into three components: a fixed effect of the firm (first level), a fixed effect of the firm based on the sector-control variable (second level), and a random sector-control effect in relation to the fixed variables of the firm by sector. The results are shown in table 2.

The results presented in table 2 show that enterprise TFP can be explained by the sector influence (product innovation) on the firm's individual capabilities.

In relation to the behaviour of the variables, capital turnover was not significant for the firm. Thus, greater investment in capital goods by the firm does not influence its productivity in the same year, possibly reflecting the longer rather than the short-term impact of investments on productivity gains in the firm.

The worker's experience in the sector, in addition to market share (via the total volume of employment in the sector) and firm size (measured by the number of jobs), were not significant for the firm's productivity, or for product innovation in the sector. Nonetheless, these variables were significant in explaining TFP at the firm level in the first estimation. Firm size and experience in the sector are important explanations of productivity change; but inter-sectoral differences do not explain productivity gains or losses in Brazilian manufacturing firms in 2005 in relation to these capabilities.

Thus, the firm size that influences productivity is proportional to the sector. An increase in firm size does not explain additional productivity gains beyond the gains obtained in other sectors, which undermines the notion that sector concentration leads to greater innovation and productivity growth. This is restricted, however, to the structure and capacity of innovation capacity of the sector, as shown in the trend of technology paths.

Export and import values display symmetrically inverse signs in the estimates. In the individual sphere of the firm in relation to the sector, imports produce additional productivity gains, while exports produce TFP gains below the sector average. In terms of product innovation in the sector, this relation remained unchanged. In relation to the sector's influence on the firm's capabilities, the impact of exports produced additional productivity gains for sectors in relation to the industry, while imports produced gains below the industry average. This shows that imports have a greater impact on productivity at the firm level. Exports generate productivity gains above the average gain of the industry, but they do not represent a generalized capability for TFP gains for all firms, since the gains are limited to certain sectors.

The share of international inputs in the productivity of Brazilian manufacturing enterprises behaves identically to the value exported, with the same significant signs. It is therefore concluded that the share of international inputs in the productivity of industrial firms depends on the sector in question.

The number of patent applications is associated with above-average productivity gains for the firm in relation

TABLE 2

Results of the regression of total factor productivity of Brazilian manufacturing firms on two levels

Variable	Estimation	t	ρ
Percentage of workers with tertiary education	-96 685	-4.76	<.0001
Average worker income	31 102	12.69	<.0001
Average time for which worker has been employed	-180 851	-2.78	0.0055
Average worker schooling	-3 565 841	-2.87	0.0041
Worker experience	-479 255	-1.01	0.3131
Innovating labour	-934 803	-12.45	<.0001
Number of patent applications	1 090 004	6.62	<.0001
Share of employment[a]	99 001 114	1.42	0.1563
Share of income[b]	683 539 815	10.78	<.0001
Contracts – No. of employees	471 315.191	1.39	0.1651
Value of exports	0.70348	21.51	<.0001
Value of imports	-209.545	-23.73	<.0001
Percentage of international inputs	187 772	1.98	0.0479
Turnover	-87 257	-0.20	0.8415
Product innovation	5 033 511	1.57	0.1170
Percentage of labour force with tertiary education*innovation	-217 299	-3.26	0.0011
Average income*innovation	-102 467	-14.24	<.0001
Average time employed *innovation	671 894	2.76	0.0059
Average schooling*innovation	17 152 108	3.35	0.0008
Experience*innovation	1 299 569	0.66	0.5089
Innovating labour force*innovation	6 096 515	33.04	<.0001
Number of patent applications*innovation	-1 780 638	-3.26	0.0011
Employment share*innovation	195 471 311	0.87	0.3845
Income share*innovation	-2 421 054 910	-12.32	<.0001
Contracts*innovation	23 283	1.57	0.1156
Value exported*innovation	-148 718	-12.71	<.0001
Value imported*innovation	540 728	30.57	<.0001
Percentage international inputs*innovation	-483 132	-1.68	0.0927
Capital turnover*innovation	382 039	0.24	0.8080
R^2	0.8326		
Adjusted R^2	0.8329		
Number of observations	25 677		
Number of observations used	15 144		
Observations lost	10 533		
Fisher test	2 597.65		<.0001

Source: Prepared by the authors on the basis of data from the Brazilian Geographical and Statistical Institute (IBGE).
* indicates a multiplication (first level by second level)

[a] Share of firm in total sector employment.
[b] Share of firm in total sector earnings.

to the sector, and for sectors in relation to the industry.[17] Product innovation in the sectors produces TFP gains above the industry average. A larger number of patents is not associated with the above-average productivity gains in firms, which are explained by sector variables rather than by product innovation.

In relation to the labour force working on innovation, TFP gains are both internal to the firm and reflect product innovation by the sectors. The sector influence on enterprise productivity gains related to innovating labour was below the sector average.

Human capital displays different results among the variables analysed. In general, the variables showed below-average productivity gains. Only time of employment in the firm and schooling produced additional productivity gains related to the presence of product innovation in the sector, which shows that learning, whether codified (present in longer schooling) or tacit (present in longer experience in the firm), is an important form of productivity gain in manufacturing firms related to the introduction of product innovations. Schooling was also associated with additional TFP gains in the firms; and income reported TFP gains related to the sector; thus, workers' pay increases productivity in certain sectors only.

[17] This result shows that some sectors generate more patents than others and obtain productivity gains above the industry average.

The firm's share in sector income moved in line with sector income, exports and the share of international inputs in the production of Brazilian manufacturing firms in 2005.

The sector differences in product innovation explain the microeconomic differences in the impact of innovation capabilities in the TFP gains achieved by Brazilian manufacturing firms in 2005. This confirms the hypothesis that innovation is systemic and explained by sector characteristics.

The sector impact on the TFP of firms and the impact of product innovation on that productivity is clear. The question that now arises is: which sectors display the most TFP gains above and below the industry average, as identified in the third part of the multilevel regression. The results are shown in table 3.

TABLE 3

Sectors impacting on TFP

Sector	Product innovation
Iron ore extraction	(+)***
Slaughtering and dressing of meat and fish products	(+)**
Production of vegetable and animal oils and fats	(-)***
Dairy products	(+)**
Milling, manufacture of cereal products and balanced animal feed	(-)*
Manufacture of refined sugar	(+)*
Manufacture of beverages	(+)**
Manufacture of tobacco products	(+)***
Manufacture of cellulose and other pastes for paper manufacture	(+)***
Manufacture of various paper, cardboard and card products	(+)**
Publishing and printing	(+)**
Production of recorded materials	(+)**
Manufacture of inorganic chemical products	(-)***
Manufacture of pharmaceutical products	(+)**
Manufacture of defensive agricultural products	(-)***
Manufacture of cement	(-)**
Production of pig iron and iron alloys	(+)**
Iron and steel	(+)**
Manufacture of piping	(+)**
Metallurgy of non-ferrous metals	(-)**
Manufacture of tractors and machinery and equipment for agriculture, poultry breeding, and the obtaining of animal products	(-)**
Manufacture of machine tools	(+)**
Manufacture of weapons, ammunition and military equipment	(-)**
Manufacture of machinery and equipment for electronic data-processing systems	(-)**
Manufacture of equipment for the distribution and control of electrical energy	(-)**
Manufacture of wires, cables and insulated electric conductors	(+)**
Manufacture of basic electronics material	(-)*
Manufacture of telephony and radio telephony equipment and television and radio transmitters	(-)**
Manufacture of machinery, equipment for electronic systems used in industrial automation and the control of productive processes	(-)**
Manufacture of clocks and watches	(+)*
Manufacture of automobiles, vans, and utility vehicles	(+)***
Manufacture of trucks and buses	(-)**
Construction, assembly and repair of railway rolling stock	(+)**
Construction, assembly and repair of aircraft	(-)***
Significant sectors	34
Positive	19
Negative	15

Source: Prepared by the authors on the basis of data from the Brazilian Geographical and Statistical Institute (IBGE).

*** ρ<0.001; ** 0.001<ρ<0.05; * 0.05<ρ<0.1
TFP: Total factor productivity.

The data contained in table 3 show that 19 sectors reported additional productivity improvements associated with product innovation in the sector. Another 15 sectors recorded below-industry-average productivity improvements relating to the presence of product innovation in the sector. In total, 34 sectors displayed productivity differences linked to product innovation, which represents 31.19% of the Brazilian industrial sectors studied in this research (109 sectors).

VII
Conclusions

The main conclusion of this study is that total factor productivity can be explained by the firm's capabilities, many of which target innovation. These capabilities are differentiated by sector and the presence of product innovation in the sector.

Some capabilities, such as exports, worker income, the number of patent applications, the firm's market share, and the share of international inputs in the firm's production, depended on the sector to have an above-industry-average impact on productivity at the enterprise level.

Other variables, such as the presence of innovating labour and the accumulation of knowledge, whether tacit (in the worker's experience in the firm) or codified (in the worker's years of schooling), and the value of imports, are influenced by the presence of product innovation in the sector, in generating additional productivity gains in the firms.

On the other hand, many variables explain TFP at the firm level, so the three levels are important for explaining how the firm' productivity is composed. If only productivity were calculated as a residual, the explanation would be that this arises from the application of technological progress in the firm's production. Nonetheless, as Hulten (2000) points out, many factors can be held responsible for the unexplained part of the firm's production function. The multilevel model constructed in this article shows that innovation (and its interdependent relationship with productivity) is systemic, and can be explained by the capabilities of the firm, sector characteristics, and the institutions and formation of social capital, identified through product innovation in the sector.

The multilevel regression model was used in response to the Schumpeterian problem of systemic innovation. The impact of product innovation in the sectors was verified through the explanation of TFP at the firm level. Sector differences are also important in explaining productivity differences, product innovation and the role of institutions and social capital in the firms.

This article contributes to the discussion of sectoral innovation systems and the formulation of public policies on innovation. The role of the industrial sector, institutions and social capital should be taken into account, since they affect the firm's capabilities and its productivity. Sectors displaying below-industry-average productivity gains warrant in-depth analysis of their characteristics and the facts that explain the smaller impact of the sector on the firms. Moreover, sectors with additional TFP gains based on sector characteristics are more productive and competitive; and industrial policy could provide economic incentives for greater international engagement by Brazilian industry.

ANNEX

Definition of the variables

The variable "Percentage of workers with tertiary education" is calculated as the percentage of persons employed that have completed a higher education course compared to the total number of workers in the firm. "Average worker income" is the average income in reais (R$) of all workers in the firm, with "Average worker schooling" being similarly defined. "Time for which worker has been employed" is the worker's number of years in the firm, his or her experience and total number of years working. "Innovating labour" is measured as the percentage of jobs involved in RDI activities, such as engineers and professionals involved in R&D (as R&D analysts and technicians), constructed by the statistics team at the Institute for Applied Economic research (IPEA) through the occupational definition. The number of workers in the firm is presented as the number of contracts, and the firm's share is calculated as its share of total employment in the sector and in total sector income. All of these variables are contained in the 2005Annual Social Information Report (RAIS).[18] As each firm defines the skill levels of its workers recorded in the RAIS, the number of workers engaged in research and development and innovation activities could be underestimated.

The variable "Number of patent applications" is measured by the number of patent applications filed with the National Industrial Property Institute (INPI) in 2005 and the two previous years (2003 and 2004) by firm i from sector j.

The export and import values are obtained from the SECEX database expressed as the dollar value in 2005.

The PIA database provided definitions for three variables. The share of international inputs used by the firm was calculated as the value of the firm's imports (converted at the average exchange rate in 2005)[19] divided by the firm's average income (in reais). The "Turnover" variable was calculated as the firm's stock of capital in the form of machinery and equipment in 2005 as a proportion of the total capital stock. The stock of capital in the PIA is calculated as the sum of assets (machinery and equipment, installations, other assets and loss of value through depreciation).

[18] The model also estimated the average time of employment and average experience (time for which the worker has been in the firm) from the RAIS database, but these variables were not significant in the estimation.

[19] The average exchange rate used was R$ 2.41, according to IPEADATA figures, which has been used in other estimates by the IPEA itself.

(Original: Portuguese)

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