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Characteristics of Brazilian innovative firms: An empirical analysis based on PINTEC—industrial research on technological innovation

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Abstract

The present paper reports on an effort to characterize Brazilian innovative firms. The characterization of the firms was based on the data from PINTEC-2000 (Industrial Research on Technological Innovation-2000). A non-parametric statistical procedure was employed which informed, in a decreasing order, that the four major predictors of innovation were exporting orientation, firm size, foreign capital origin, and inter-industry differences. The main determinants of whether firms introduced a new process in the market were foreign or mixed capital origin, sector effect, and export orientation. When the introduction of new products in the market was assessed, the major determinants were export orientation and foreign capital origin.

JEL classification: 030; C45

Keywords: Technological change; Research and development; Neural networks and related topics

1. Introduction

The aim of the present paper is to analyze the characteristics of Brazilian innovative firms. This analysis is based on the information obtained from PINTEC-2000 (Industrial Research on Technological Innovation conducted by IBGE—Brazilian Institute of Statistics and Geography). PINTEC is the most comprehensive and most recent Brazilian research on product and process innovations, including 72,000 firms with 10 or more employees. The study period extended from 1998 through 2000.

Empirical literature is vast on the determinants of innovative activities. The studies carried out by Cohen and Levin (1989), Cohen (1995) and Kumar and Siddharthan (1997), Evangelista et al. (1998)

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put forward several theoretical arguments and results obtained through empirical tests for industrialized and developing countries. Quite often, innovative activities, or the intensity which they are undertaken, are explained by the firms' characteristics, market structure, inter-industry differences, and by appropriability and demand conditions. Some Brazilian empirical studies set out to examine innovative activities as well, among which we have those conducted by Macedo and Albuquerque (1999), Quadros et al. (2001), Andreassi and Sbragia (2002), and Sbragia et al. (2002) to cite a few. However, this is the first time a study evaluates the Brazilian industry as a whole. The present study is extremely worth since it fosters the improvement of research studies on technological changes and innovations, and helps to formulate policies for the promotion of Brazil's technical advancement. Moreover, it also allows for future comparisons with international studies that have been underway in different countries.

The analysis initially focuses on general innovation, without distinguishing between process or product innovations or the scope of these innovations (for the market or only for the firm).[1] Later on, the set of innovative firms is selected and the characteristics of process and product innovators are assessed separately. For each of these subsets, we attempt to identify the characteristics that discriminate between firms which innovate for the market and those which do it only for the firm. Therefore, we used a non-parametric statistical procedure that consisted of classification trees and regression.

The paper contains four main sections, in addition to the introduction. The first section presents the PINTEC database and the descriptive analysis of the firms' characteristics. The second section gives an overview of the statistical method used. The third section describes the results and indicates the firms' characteristics that best explain general innovations, in addition to the results regarding process and product innovations. Our concluding remarks are presented in the last section.

[1] Innovations only for the firm mean that the product or process is regarded as innovation only for the firm at issue, that is, if it has already been introduced by other(s) firm(s), but not by the one at issue. Innovations for the market mean that the product or process was still unknown on the market. Obviously, every innovation for the market is also an innovation for the firm, but in this case, innovations for the market prevail.

Table 1
Dependent variables

Variable	Transformations (categorical variables)
No innovation/innovation	0 = No innovation; 1 = Innovation
Innovation for firm/innovation for market (process)	0 = Innovation only for firm; 1 = innovation for market
Innovation for firm/innovation for market (product)	0 = Innovation only for firm; 1 = innovation for market

2. Data source and descriptive analysis of information

The empirical analysis was based on the micro-data obtained from PINTEC 2000, for the period between 1998 and 2000. The aim of the survey is "*the construction of national indicators of technological innovation in Brazilian firms following international methodologies and conceptualizations*" (IBGE, 2002, p. 12). The sample consists of a set of 10,658 firms, whose results were expanded to 72,005 industrial businesses.[2] The firms were characterized according to their size (number of employees), their capital origin, exporting orientation and organizational structure. Additionally, firms are identified according to the sector or industrial division to which they belong. All this information is available from PINTEC, except for the one about exporting orientation, which is provided by SECEX—Foreign Trade Secretariat of the Ministry of Development, Industry and Commerce (MDIC).[3] The construction of empirical variables, as well as the transformations used for statistical estimations, is described in detail in Tables 1 and 2.[4]

Usually, the undertaking of innovative activities, or the intensity which they are undertaken, is explained based on the firms' characteristics, market structures,

[2] According to IBGE's Annual Industrial Research on the number of firms with five or more employees, industrial businesses account for nearly 60% of the number of firms, 94% of the number of employees, and 98% of the value for industrial transformation.

[3] SECEX is responsible for the data survey on the movement of the international trade of Brazilian-based companies.

[4] The two-digit National Economic Activity Classification (CNAE) adopted by IBGE was utilized. This classification allows distributing firms into 32 sectors of economic activity. This classification is compatible with the one proposed by the International Standard Industrial Classification—ISIC.

Table 2
Variables for characterization of firms

Variable	Transformations
Firm size	
Total number of employees	Logarithm
Number of employees (SIZE)	Categorical variables 1 = 10 to 29 2 = 30 to 49 3 = 50 to 99 4 = 100 to 249 5 = 250 to 499 6 = 500 or more
Exporting orientation (EXPORT_1) Exporting firms—SECEX	0 = Does not export 1 = Exports occasionally 2 = Exports continuously
Firm status (FStatus)	1 = Independent 2 = Controlling 3 = Controlled 4 = Related
Origin of controlling capital (OCC)	0 = National 1 = Foreign 2 = Mixed
Sector effects	
Classifications according to technological opportunities (staff qualified in R&D/SIZE—OPORT1)	1 = Low opportunity 2 = Medium low opportunity 3 = Medium opportunity 4 = High opportunity
Obtained by way of calculation (INTENS)	1 = Intensive training in capital and technology 2 = Intensive training in labor 3 = Intensive training in natural resources
Production factor intensity (Moreira and Najberg, 1998)	1 = Capital goods 2 = Durable goods 3 = Non-durable goods 4 = Intermediate goods
End-use categories (EU_CAT)	CNAE–IBGE classification

inter-industry differences, and on appropriability and demand conditions. According to Cohen (1995), the economic literature positively associates firm size with innovative activity due to the greater credit availability for or self-financing of these activities, large-scale gains and the scope for the formation of Research and Development departments.

Capital origin is important for the determination of the firm's technological effort since it is related to the competitive status taken on by foreign firms in a domestic market. According to Kumar and Siddharthan (1997), multinational firms own a set of intangible assets, such as world-famous brands, unlimited access to technology and to managerial and organizational training programs. Because of that, the competitive strategy adopted by a multinational firm in a local country is likely to be nonprice-based. This nonprice-based competition would be contingent upon marketing expenses, quality control and product development, in addition to a series of consumer services. Nevertheless, multinational firms tend to concentrate their research activities in their home country. Technological efforts in developing countries like Brazil are usually targeted at adapting technology and products to the domestic market.[5] Even so, according to this competitive framework it is possible to establish a positive relationship between the undertaking of technological activities and the foreign capital origin.

There are several theoretical arguments regarding the relationship between exporting orientation and innovative activity. Braga and Willmore (1991), Bernard and Jensen (1999), Ropper and Love (2002), among others, select several arguments in different orders of causality between exporting orientation and innovative activity, denoting a possible simultaneity problem between innovation and export. As exporting orientation favors innovative activity, exposure to international market competition would encourage firms to engage in innovative activities. This would meet the most stringent demands and the most intense competitive pressures observed in the international market. It is also argued that exports, by expanding the firms' markets, increase the profits of innovative activities as they abate its costs. Braga and Willmore (1991) believe the first line of argument is the one that best suits the Brazilian case, as Brazil is a developing country. According to this argument, Blalock and Gertler (2004) study the relationship between exports and efficiency for Indonesian manufacturing firms and find that firm-level productivity is improved once the firms start exporting. Following these authors, a possible

[5] A possible justification for this argument is that multinational firms use world platforms for their products. This may discourage firms from making innovations in their home country, encouraging them to only adjust to the domestic market and introduce their products in it.

explanation is that firms that actively participate in the export market are exposed to advanced technology and increased competition. Bernard and Jensen (1999) provide empirical evidence supporting the hypothesis of an inverse direction of causality. These authors find evidence that larger and more productive non-exporting firms are those with a greater tendency to export, which supports the hypothesis that the remarkable performance of exporters compared to non-exporters may be a consequence of self-selection of the best firms into the export market. Consequently, these pieces of evidence back up the hypothesis that technological and innovative activities allows firms easier access to more competitive international markets, by providing them with distinct technical and managerial capacities.

In addition to these characteristics, the fact that the firm belongs to a national or international business group is also a determinant of innovative activity. This hypothesis is tenable due to the possible access of the firm to financing sources that are internal to the group, its participation in the group's developmental strategies or due to the correlation of this characteristic with the firm's foreign capital origin. Finally, an inter-industry difference is often observed as to how deeply industries may be involved in innovative activities. Most of the arguments that attempt to explain such differences are related to the various opportunities for technological development perceived by the industries, and also to cross-section studies such as the one underway, which may indicate associations with sectoral demand pressures (Dosi, 1988).

Although this general analysis of innovation is important, the characteristics that define a firm as being a process or product innovator may be quite different. Because of this, process and product innovations are assessed separately. Moreover, as mentioned previously, the place where these innovations occur (at the market or at the firm level) is also taken into consideration.

Table 3 shows the distribution of innovative and non-innovative firms according to their size, capital origin, exporting orientation and organizational structure. The innovation rate of Brazilian industry, according to PINTEC, between 1998 and 2000, was 31.5%. However, we may observe that this rate is significantly higher for some firm categories. With regard to firm size groups, for instance, there is an evidently increasing relationship between firm size and innovation. Among very

Table 3
Distribution of innovative and non-innovative firms according to their characteristics

	General innovation						Process innovation						Product innovation					
	No innovation		Innovation		Total		Firm		Market		Total		Firm		Market		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Firm size																		
Very small	35,173	74.7	11,909	25.3	47,082	65.4	8,790	94	563	6	9,353	51.5	5,175	83.5	1,025	16.5	6,200	49
Small	10,656	62.4	6,430	37.6	17,086	23.7	4,564	90.1	504	9.9	5,068	27.9	2,768	76.3	860	23.7	3,628	28.7
Medium	3,147	48.6	3,329	51.4	6,476	9	2,299	81.7	515	18.3	2,814	15.5	1,411	69.7	613	30.3	2,024	16
Large	332	24.4	1,029	75.6	1,361	1.9	507	54.8	418	45.2	925	5.1	331	41	477	59	808	6.4
Capital origin																		
National	48,537	69.4	21,353	30.6	69,890	97.1	15,594	91.1	1,528	8.9	17,122	94.3	9,203	79.6	2,361	20.4	11,564	91.4
Foreign	569	34.1	1,100	65.9	1,669	2.3	443	51.5	417	48.5	860	4.7	369	41.7	515	58.3	884	7
Mixed	201	45.2	244	54.8	445	0.6	123	69.1	55	30.9	178	1	112	53.1	99	46.9	211	1.7
Exporting orientation																		
Non-exporting	43,709	72.7	16,407	27.3	60,116	83.5	12,457	93.9	804	6.1	13,261	73	7,157	85.1	1,253	14.9	8,410	66.4
Exports occasionally	2,825	53.3	2,473	46.7	5,298	7.4	1,548	80.5	374	19.5	1,922	10.6	1,000	63.5	574	36.5	1,574	12.4
Exports continuously	2,773	42.1	3,818	57.9	6,591	9.2	2,154	72.4	822	27.6	2,976	16.4	1,527	57.1	1,148	42.9	2,675	21.1
Organizational structure																		
Independent	48,198	69.5	21,178	30.5	69,376	96.4	15,358	90.7	1,566	9.3	16,924	93.2	9,073	78.9	2,425	21.1	11,498	90.8
Controlling	167	39.7	254	60.3	421	0.6	141	64.7	77	35.3	218	1.2	113	54.9	93	45.1	206	1.6
Controlled	663	41.3	942	58.7	1,605	2.2	444	58.6	314	41.4	758	4.2	355	47.7	389	52.3	744	5.9
Related	279	46.3	323	53.7	602	0.8	216	83.4	43	16.6	259	1.4	143	68.1	67	31.9	210	1.7

small and small firms only 25% and 38%, respectively, innovated between 1998 and 2000, whereas for large firms the rate of innovation was 76%.[6] In terms of capital origin, innovative firms with foreign capital (66%) predominated over those with mixed capital (55%). When exporting orientation is analyzed, we may note that those firms that exported occasionally and continuously have a rate of innovation of 47 and 58%, respectively, against only 27% for non-exporting firms. As far as organizational structure is concerned, innovative firms often fall into the categories of business groups.

According to PINTEC, 18,160 firms were process innovators (25% of the total number of industrial businesses and 80% of the total number of innovative firms), which 16,160 were process innovators only for the firm, whereas 2001 were process innovators for the market. Among the 12,569 product innovators (17% of the total number of industrial businesses and 55% of the total number of innovative firms), 9684 were product innovators only for the firm, whereas 2975 were product innovators for the market.

A positive relationship was noted between firm size and the rate of innovation for the market both in process and product innovations. In case of process innovation, 45.2% of large firms innovated for the market in comparison with only 15.9% of very small and small firms. In case of product innovation, 59% of large firms innovated for the market comparatively to 40.2% of very small and small firms.

Brazilian firms are mostly innovative only for the firm: 91.1% and 79.6% in process and product innovations, respectively. When capital origin is regarded as a reference in foreign firms, the rate of innovation for the market is higher (48.5% in case of process innovation; and 58.3% in case of product innovation). The rate of innovation for the market is higher for exporting firms in relation to non-exporting firms. This is valid for both process and product innovations. Firms that export continually innovate for the market, with rates of 27.6% for process innovation and 42.9% for product innovation. Organizational structure is slightly different in process and product innovations. As to process innovations, the rate of innovation for the market is higher than the average for the industry in case of controlled firms (41.4%) and controlling firms (35.3%). As to product innovation, however, the innovation rate is not higher than the average only in case of independent firms. The rate of product innovation for the market is 52.3% in case of controlled firms, 45.1% in case of controlling firms, and 31.9% in case of related firms. Independent firms, which are the overwhelming majority, innovated only for the firm (90.7% in case of process innovation and 78.9% in case of product innovation).

Table 4 shows the sectoral distribution of the firms. Three taxonomies were used for this classification: (i) intensity of the production factor (Moreira and Najberg, 1998); (ii) technological opportunities for the sector (whose calculation was based on the ratio between the staff qualification in R&D department[7] and the number of employees in the sector) and iii) end-use category for the goods.

With regard to the intensity of the production factor, the most innovative firms are those that invest intensively in capital and technology: 39.8%, against 23.1 and 30.4% of the firms intensive in natural resources and labor, respectively. When firms are classified according to technological opportunities, we note an increasing relationship between innovation and the level of technological opportunity for the sector. And finally, sectoral distribution according to end-use category shows that there is a relatively higher rate of innovative firms only for the capital goods sector (41.1%), whereas for the remaining end-use categories, the rate of innovative firms was around 30%.

By respecting the differences between process and product innovations for the market, no remarkable differences are seen between the order of the different rates when we consider the varying sectoral distribution. Sectors regarded as innovative for the market are those whose technological opportunity is medium low, medium and high, those that invest intensively in capital and technology, and those that manufacture intermediate and capital goods.

Thus, this preliminary descriptive analysis revealed that firm size, exporting orientation and foreign capital origin are important determinants of innovation. The

[6] In this descriptive analysis the firm size categories are: "Very small" for firms with until 19 employees, "Small" for firms in the range of 20–99 employees, "Medium" for firms in the range of 100–499 employees and, "Large" for firms with 500 or more employees.

[7] The staff includes part-time and full-time university graduates or professionals with a master's or doctor's degree. The sectors related to each of these categories are shown in the Appendix B.

Table 4
Sectoral distribution of innovative and non-innovative firms

	General innovation						Process innovation						Product innovation					
	No innovation		Innovation		Total		Firm		Market		Total		Firm		Market		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Intensity																		
Natural resource	17,538	76.9	5,281	23.1	22,819	31.7	4,062	88.7	515	11.3	4,577	25.2	2,291	84.8	412	15.2	2,703	21.4
Labor	15,994	69.6	6,977	30.4	22,971	31.9	5,566	94.5	327	5.5	5,893	32.5	2,939	90.2	318	9.8	3,257	25.7
Capital	15,775	60.2	10,439	39.8	26,214	36.4	6,532	84.9	1,158	15.1	7,690	42.3	4,453	66.5	2,245	33.5	6,698	52.9
Technological opportunity																		
Low	43,021	71.1	17,499	28.9	60,520	84	13,494	91.1	1,321	8.9	14,815	81.6	7,306	84.5	1,345	15.5	8,651	68.3
Medium	4,978	54.9	4,089	45.1	9,067	12.6	2,198	80.2	542	19.8	2,740	15.1	1,861	58.7	1,308	41.3	3,169	25
Medium–high	1,033	55.6	826	44.4	1,859	2.6	374	76.3	116	23.7	490	2.7	362	62.6	216	37.4	578	4.6
High	276	49.4	283	50.6	559	0.8	94	81	22	19	116	0.6	156	59.5	106	40.5	262	2.1
Use of goods																		
Capital	7,485	58.9	5,216	41.1	12,701	17.6	3,228	87.7	452	12.3	3,680	20.3	2,184	65.3	1,160	34.7	3,344	26.4
Durable	4,608	66.6	2,314	33.4	6,922	9.6	1,687	93	127	7	1,814	10	1,146	85.5	194	14.5	1,340	10.6
Non-durable	20,501	70.1	8,765	29.9	29,266	40.6	6,773	91.2	657	8.8	7,430	40.9	3,821	87.8	530	12.2	4,351	34.4
Intermediate	16,714	72.3	6,403	27.7	23,117	32	4,472	85.4	764	14.6	5,236	28.8	2,532	69.9	1,091	30.1	3,623	28.6
Total	49,308	68.5	22,698	31.5	72,006	100	16,160	88.9868	2,000	11.013	18,160	100	9,683	76.4971	2,975	23.5029	12,658	100

rate of innovative firms also increases when technological opportunity is considered for the sector, as well as for sectors intensive in capital and intermediate goods.

3. Empirical analysis

The estimates to be made in the present paper are supposed to answer three questions:

(1) What are the firms' characteristics that best define whether a firm is innovative or non-innovative?
(2) What are the characteristics of innovative firms that explain the probability of a firm being a process innovator for the market or being a process innovator only for the firm?
(3) What are the characteristics of innovative firms that explain the probability of a firm being a product innovator for the market or a product innovator only for the firm?

For the analysis, we use a statistical tool that is relatively infrequent in studies related to this field of research: 'classification trees'. A classification tree is a rule for predicting the class of an object (dependent variable) from the values of its predictor variables, allowing various possibilities of interaction between these variables to be checked. Classification trees are not subject to restrictions upon the functional form of the joint probability distribution of variables and upon the supposed exogeneity of predictor variables. It is a non-parametric statistical procedure based on exhaustive search algorithms. The results presented are hierarchical and flexible structures that allow for the observation of distinct relationships between the dependent variable and several subsets of explanatory variables.

In the present study, we used the QUEST (Loh and Shih, 1997) estimation method.[8] This method allows for binary partition of nodes (thus avoiding extreme complexity), also allowing for the insertion of different classification costs for the categories[9] and reduction of

8 The most popular methods are CHAID (chi-square automatic iterated detection) proposed by Kass (1980), C&RT (classification and regression tree), by Breiman et al. (1984) and QUEST (quick, unbiased, efficient, statistical tree) proposed by Loh and Shih (1997).

9 Misclassification costs may be symmetric or not. The researcher may assign a heavier penalty for a given type of mistake, for instance, for classifying an innovative firm as non-innovative.

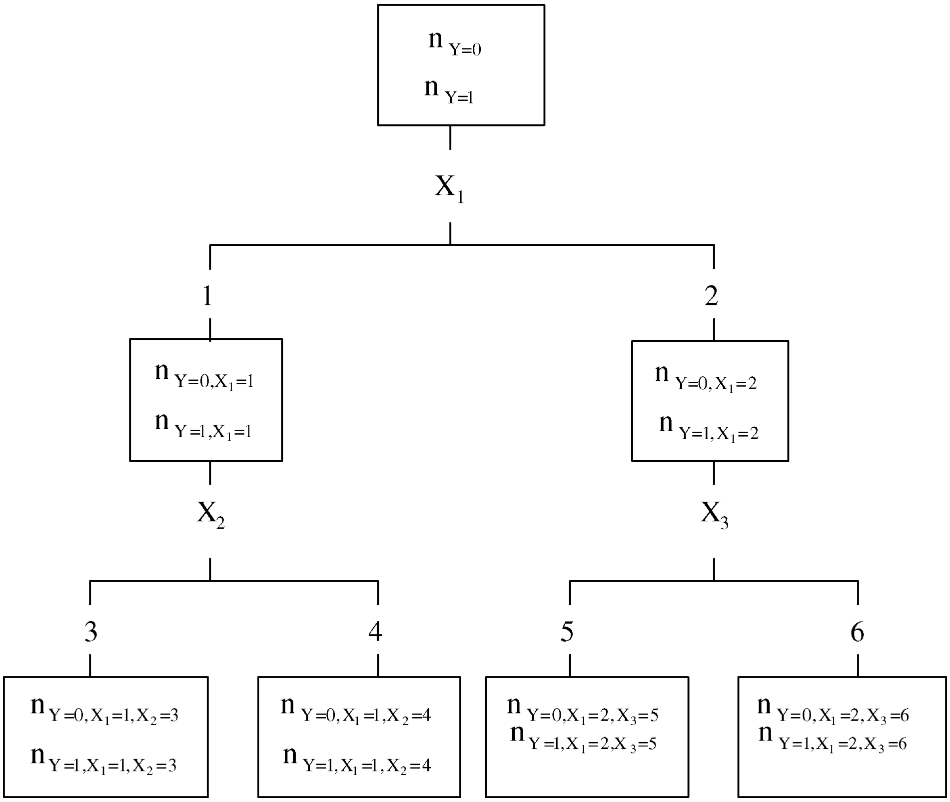


Diagram 1. Classification tree.

the tree (*pruned tree*) based on a cost/benefit ratio.[10] Classification trees were estimated for each of the dependent variables. For robustness, estimates were also made via *logit* models (see Appendix A).[11]

Diagram 1 shows a binary partition tree with three levels of classification. The tree is composed of 'nodes'. There are other nodes between the root node and the terminal node, forming the classification branches. The root node contains all the information on the sample and represents dependent variable *Y*, with the number of observations for each of the categories (0 and 1) or classes. As the tree expands, the data are branched into mutually exclusive subsets. These subsets are branches of the tree. After that, the sample is divided according to the best predictor of *Y*—explanatory variable X_1. Node 1 presents the subset of information on *Y*, classified according to a rule of $X_1 < c$ type, whereas node 2 classifies the information on *Y* according to rule $X_1 \geq c$, in which c is any number or category corresponding to variable X_1. Nodes 1 and 2 contain information about the frequencies of variable *Y* related to each subgroup defined according to combinations (Y, $X_1 < c$) and (Y, $X_1 \geq c$). Nodes 1 and 2 are the 'parents' of nodes 3, 4, 5 and 6. For node 1 the best predictor is variable X_2, whereas for node 2 the best predictor is variable X_3. These 'child nodes', obtained from the division according to predictors X_2 and X_3, contain information about the frequencies of variable *Y* related to each subgroup defined according to the combinations (Y, X_1, X_2) and (Y, X_1, X_3). These final 'nodes', found at the end of the tree, are called terminal nodes.

[10] The complexity of the classification tree analysis may be a cost factor for the researcher. Thus, as the tree expands, it produces risk minimization at the one hand, and increased complexity on the other hand.

[11] Further details about the logit models and about the comparison with the results provided by classification and regression trees are shown in Appendix A.

The measure of capacity, or predictive accuracy of a tree is built from a classification matrix given by:

Predicted value	Value observed	
	Class A	Class B
Class A	N_{AC}	N_{AM}
Class B	N_{BM}	N_{BC}

in which N_{jC} is the number of observations correctly classified with j = A, B; N_{jM} is the number of observations incorrectly classified with j = A, B; $N_j = N_{jC} + N_{jM}$ with j = A, B.

This measure is equal to 1—Risk, in which Risk (or apparent error) is given by:

$$\text{RISK} = R(T) = \left(\frac{N_{AM} + N_{BM}}{N_A + N_B}\right) \times 100.$$

4. Results of the analysis using classification trees

This section is divided into three subsections: the first one analyzes general innovation; the second one deals with process innovation for the market; and the third one is concerned with product innovation for the market.

4.1. General innovation

Tables 5 and 6 show the statistical summaries of Trees 1 and 2.[12] These trees have symmetric classification costs, the first one having minimal risk and the second one being reduced according to the cost/complexity parameter. As we may see the estimated risk for these trees is 0.29.[13] According to Tree 1, the terminal nodes, in decreasing order, with a higher rate of innovative firms are indicated by the *profit* column in the tables.[14] The first node with a higher rate of innovative firms is the number 9, corresponding to exporting firms, with 100 or more employees, and with foreign or mixed capital. The second node, number 20, corresponds to exporting firms, with 250 or more employees, with domestic capital. The third node with a higher rate, number 18, is concerned with exporting firms with over 19 and less than 100 employees (small firms) belonging to sectors with medium low and medium high technological opportunity. The fourth node, number 29, corresponds to Brazilian exporting firms, with less than 250 employees, belonging to sectors intensive in capital and technology.

On the other hand, by analyzing the classification power of terminal "nodes", it is possible to obtain information about the characteristics of non-innovative firms. These firms are represented by the nodes 21 and

Table 5
Statistical summary of the minimal risk tree (Tree 1)

Nodes	Frequency	Rate	Profit
9	937	1.3	0.75
20	1,557	2.2	0.67
18	1,327	1.9	0.62
29	973	1.4	0.56
28	950	1.3	0.53
31	838	1.2	0.52
25	729	1.0	0.51
14	416	0.6	0.51
24	777	1.1	0.51
30	919	1.3	0.45
16	2,622	3.7	0.45
13	2,532	3.5	0.44
23	4,483	6.3	0.36
27	131	0.2	0.35
26	1,372	1.9	0.28
21	50,195	70.2	0.25
32	725	1.0	0.19

Classification matrix

Predicted value	Observed value	
	Non-innovative	Innovative
Non-innovative	45, 641	17,338
Innovative	3, 473	5,031
Risk	0.291132	

[12] Inside the trees Não Inova means no innovation, and Inova means innovation.

[13] This error estimate is lower than the naive estimate of 0.5 and also slightly lower than the estimate that all firms are non-innovative.

[14] It should be noted that the objective of the tree would be the strict classification on each node. This means that the information on each of the nodes should depict only one of the classes (non-innovative or innovative). Therefore, if, for instance, a node contains a rate of innovation greater than 50%, this shows that the node is more likely to represent the class of innovative firms according to the classification proposed by the branch to which it belongs. Thus, the measure of risk on the node is the amount that complements the percentage of innovative firms on the node. The profit table indicates the nodes on which the level of homogeneity is greater, which means that classification is clearer on these nodes and therefore less amenable to risks.

Table 6
Statistical summary of the pruned tree (Tree 2)

Nodes	Frequency	Rate	Profit
7	937	1.3	0.91
10	1,557	2.2	0.73
6	2,408	3.4	0.63
11	973	1.4	0.57
12	919	1.3	0.55
5	4,723	6.6	0.45
2	59,966	83.9	0.30

Classification matrix

Predicted value	Observed value	
	Non-innovative	Innovative
Non-innovative	46, 904	18,704
Innovative	2, 210	3,665
Risk	0.292573	

32, which correspond to non-exporting firms, with less than 50 employees, belonging to sectors with low or medium low technological opportunity, or those non-exporting firms with 50–99 employees belonging to the durable goods sectors, respectively.

The combined analysis of Trees 1 and 2 shows that, in hierarchical terms, the main variable used for the classification of firms is concerned with whether they are exporting or not, as well as with their size. Afterwards, sector effects and capital origin are also important.[15] This information is summarized in the pruned tree, since this tree shows the reduced classification power of the variables used to characterize innovative firms in the “child nodes” of the branch of non-exporting firms.

Trees with asymmetric classification costs were also estimated.[16] In the tree which a heavier penalty was assigned for the misclassification of a non-innovative firm as innovative, the model explored the innovative branch of the tree, that is, the class of exporting firms. First of all, it is important to emphasize the importance of the continuous aspect of the exporting activity; and secondly, the importance of firms that export continuously, with over 250 employees, classified as innovative firms. The main innovative terminal node of the tree informs that 81.7% of the firms with 500 or more employees which exported continuously were innovators. The firms with 250–499 employees which export continuously are remarkably more likely to innovate if they belong to the capital goods sector. In the tree to which a heavier penalty was assigned for the misclassification of an innovative firm as non-innovative, the model explored the non-innovative branch of the tree, in this case, the class of non-exporting firms. The basic information produced by this tree is that in case of non-exporting firms, the size is what matters in the classification of a firm as innovative. Firms with over 100 employees are more likely to be innovative.

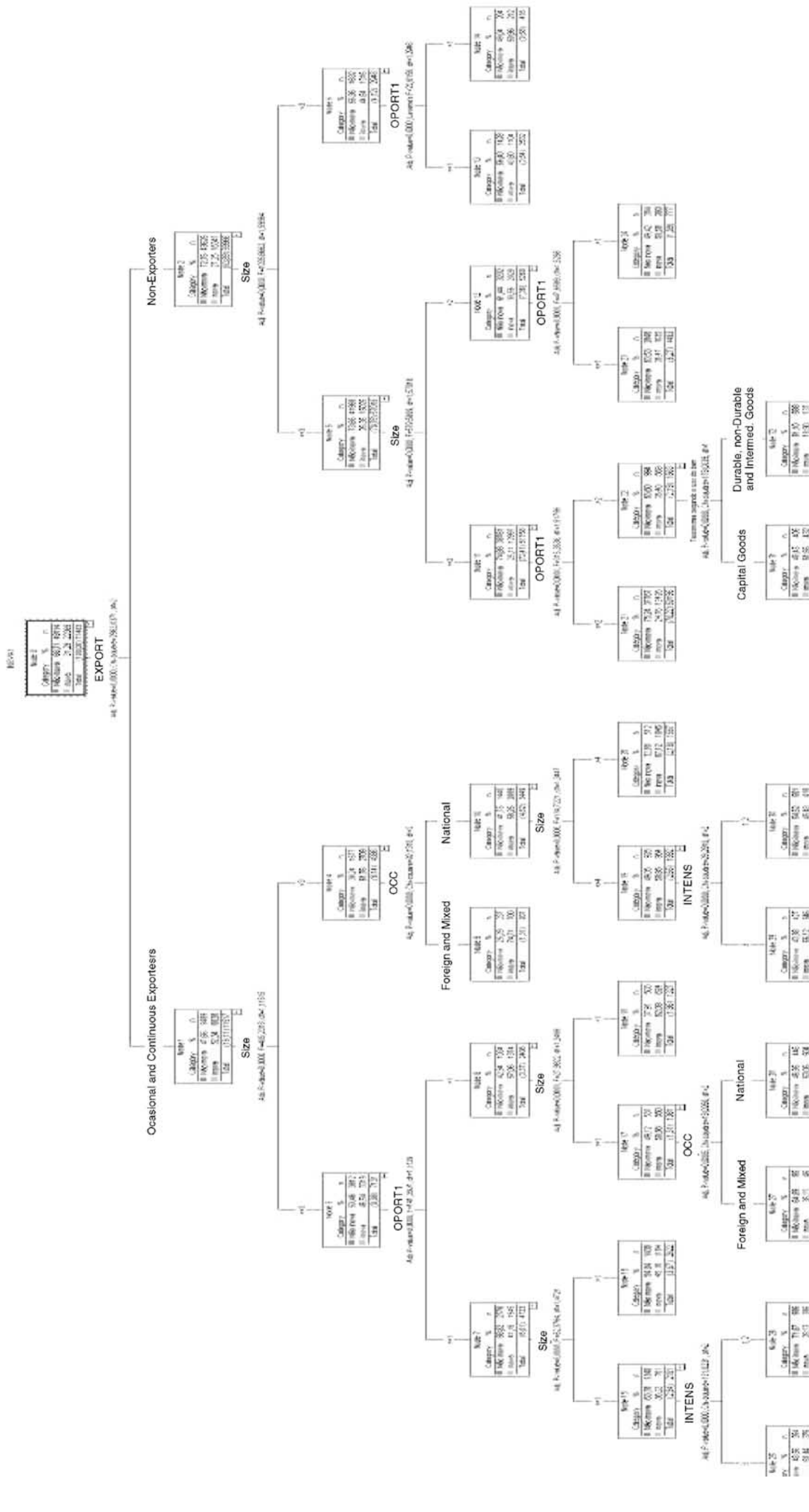
These results can be more clearly understood by separately observing the two major branches of the estimated trees. In the branch of non-exporters, the correlation between size and sectoral effect dominates the variation of this relationship. A positive relationship is observed in all levels of this branch between firm size and the probability to innovate, and sectoral categorizations are a distinctive characteristic of these interactions. In other words, in case of non-exporting firms, size combined with sectoral differences define the competitive edge of these firms in the domestic market.

Before analyzing the branch of exporting firms, we should make some preliminary considerations on these firms. Given the structure of the Brazilian export portfolio, in general, exporting firms are expected to have a low technological profile. In general, we should also expect a larger concentration of very small and small firms that export labor-intensive and natural resource-intensive goods, and which therefore have a low technological quality. Indeed, the technological profile of these firms is different from that of large firms in these sectors. However, this does not necessarily occurs for exporting firms that manufacture goods of higher technological quality, which belong to sectors with medium and high technological opportunities.[17] In some of

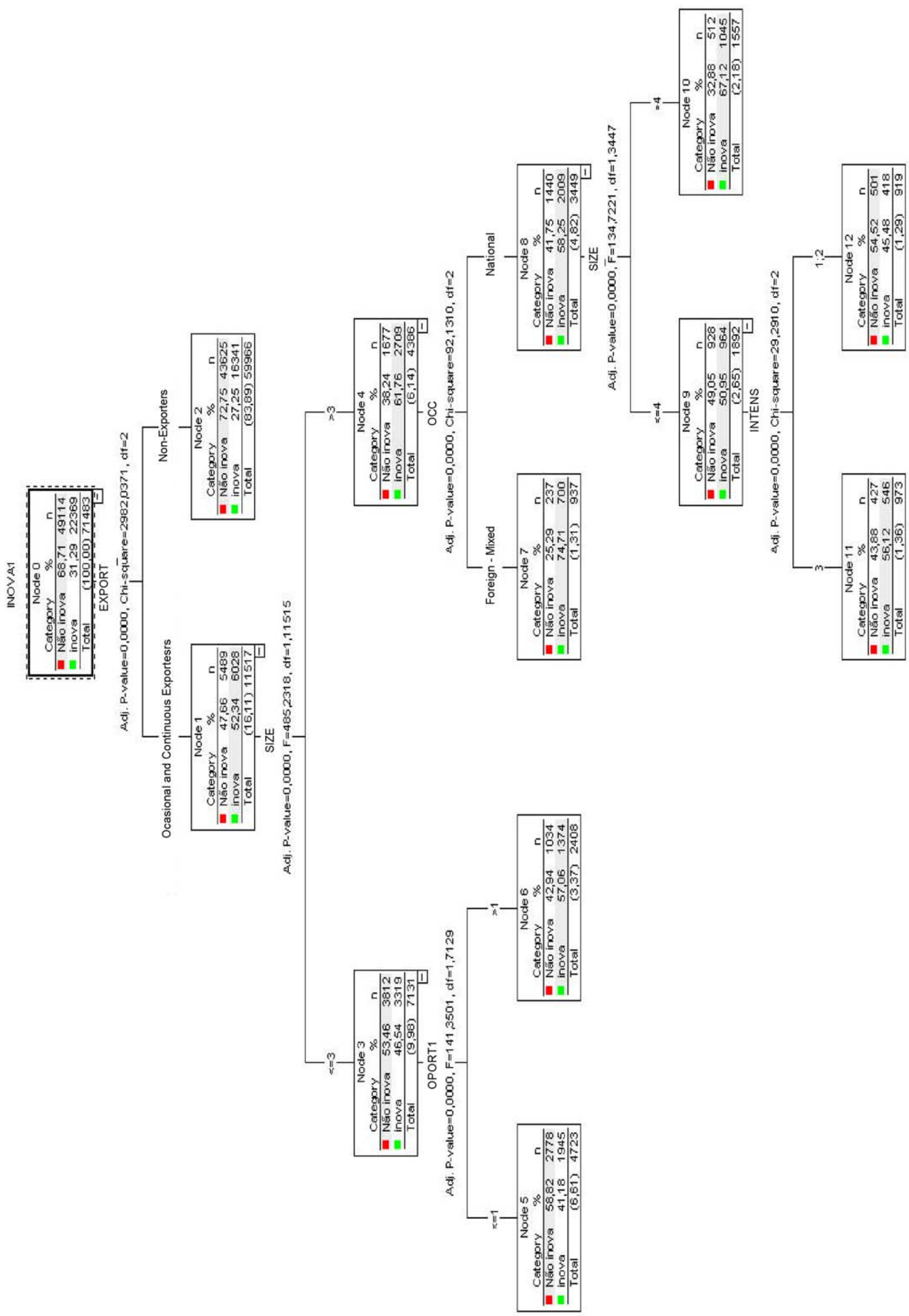
[15] Such results are corroborated by the estimates of the *logit* model (Table A.1 in the Appendix A).

[16] A cost equal to two was considered for the misclassification of innovative firms as non-innovative, and a cost of one was used for the misclassification of non-innovative firms as innovative. We also made an estimation by inverting this relationship. These results are available upon request.

[17] Evidence related to these statements was given by Mota Veiga and Marwald (1998) when they analyzed the behavior of small and medium-sized Brazilian exporting firms for 1996. According to this study, the very small, small and medium-sized firms that export products from sectors classified as specialized suppliers or R&D Intensive have a relatively homogeneous share in the flow of exports comparatively to large firms in these sectors.



Tree 1. General innovation—minimal risk—symmetric costs.



Tree 2. General innovation—pruned tree—symmetric costs.

these sectors, the technological profile of small and medium-sized firms is quite close to that of large firms, and the relationship between size and exporting orientation for this subset of firms is not that important. Bearing this in mind, it is possible to understand the poor relevance of the variable *size* in interactions produced by the trees for the sub-branch of exporting firms with less than 100 employees, in which sectoral interactions with exporting orientation predominate.

In case of exporting firms with 100 or more employees, the different interactions between size and capital origin, in order to define the nodes that represent the innovative firms, reflect the different interaction between the probability of these firms to export and their size.[18] The fact that the largest national exporting firms operating to natural resource-intensive or low technological opportunity sectors, and that larger foreign-capital exporting firms are predominantly found in capital-and-technology-intensive sectors, explains the higher proportion of innovative and foreign-capital exporting firms relative to the number of innovative domestic capital exporting firms. Thus, the classification for innovative firms in this branch of the tree is basically given by the correlation between innovation and export. The differences in the nodes only reflect the different forms of interaction between size and capital origin, in addition to the technological opportunities offered by the respective sectors.

4.2. Innovation for the market and innovation only for the firm

4.2.1. Process innovation

Tables 7 and 8 show the statistical summaries of Trees 3 and 4.[19] These trees have symmetric classification costs, the first of which presents minimal risk whereas the second one is reduced according to the cost-complexity parameter. The estimated risk for these trees is 0.10.[20] According to the estimations for Tree 3, the terminal nodes, in decreasing order, with a higher rate of innovators for the market are indicated by the *profit* column in the tables. The two nodes, numbers 11 and 14, with higher rates of innovators for the market correspond to firms with foreign capital origin, belonging to the intermediate goods sector. The distinction

Table 7
Statistical summary of minimal risk tree (Tree 3)

Nodes	Frequency	Rate	Profit
11	68	0.4	0.79
14	100	0.6	0.70
16	124	0.7	0.64
12	99	0.6	0.43
15	179	1.0	0.41
13	160	0.9	0.41
10	50	0.3	0.26
6	188	1.1	0.23
2	16,897	94.6	0.09

Classification matrix

Predicted value	Observed value	
	Market	Firm
Market	203	89
Firm	1, 710	15,863
Risk	0.1007	

Table 8
Statistical summary of the pruned tree (Tree 4)

Nodes	Frequency	Rate	Profit
7	68	0.4	0.79
10	100	0.6	0.70
8	99	0.6	0.43
9	160	0.9	0.41
3	541	3.0	0.38
2	16,897	94.6	0.09

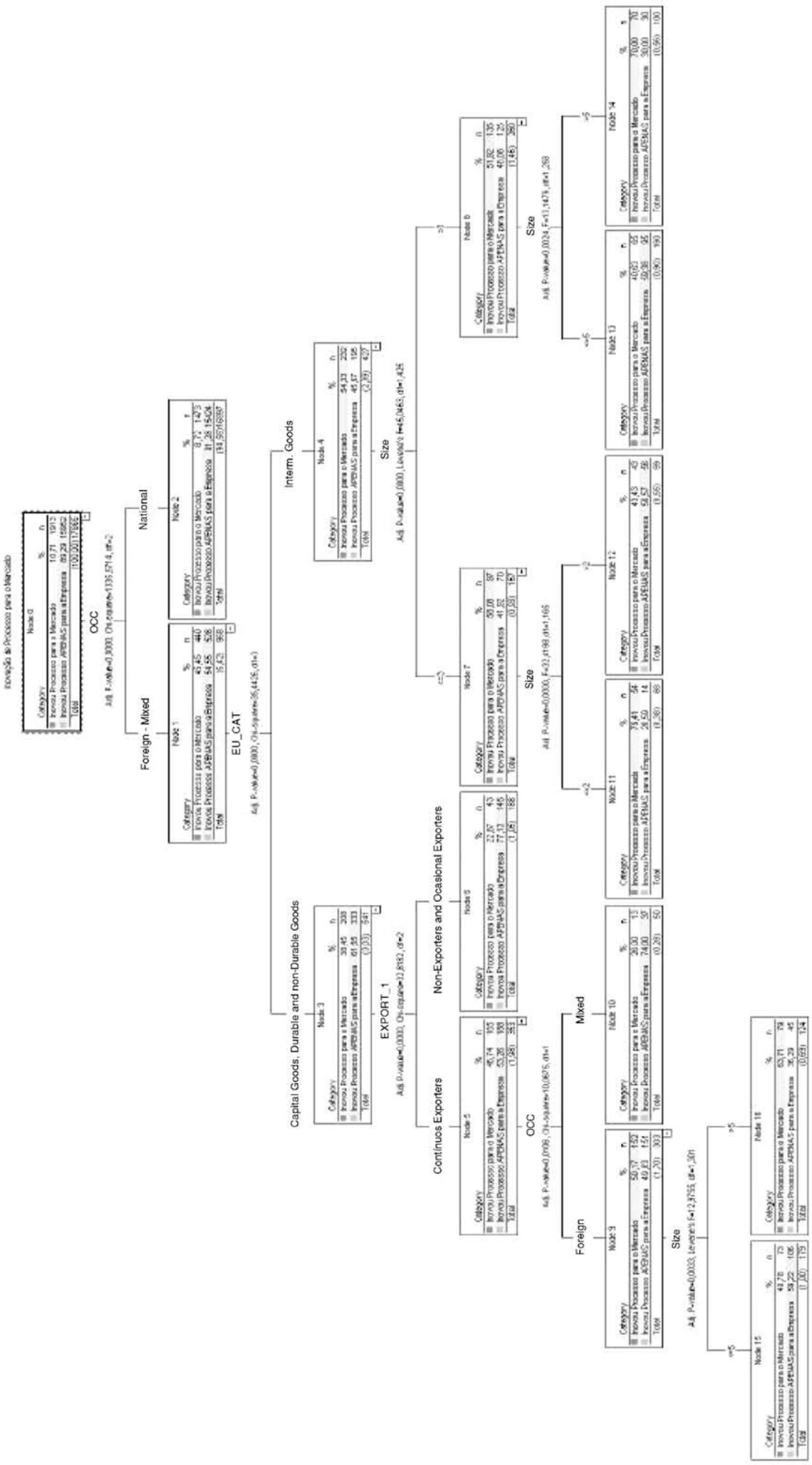
Classification matrix

Predicted value	Observed value	
	Market	Firm
Market	124	44
Firm	1, 789	15,908
Risk	0.102603	

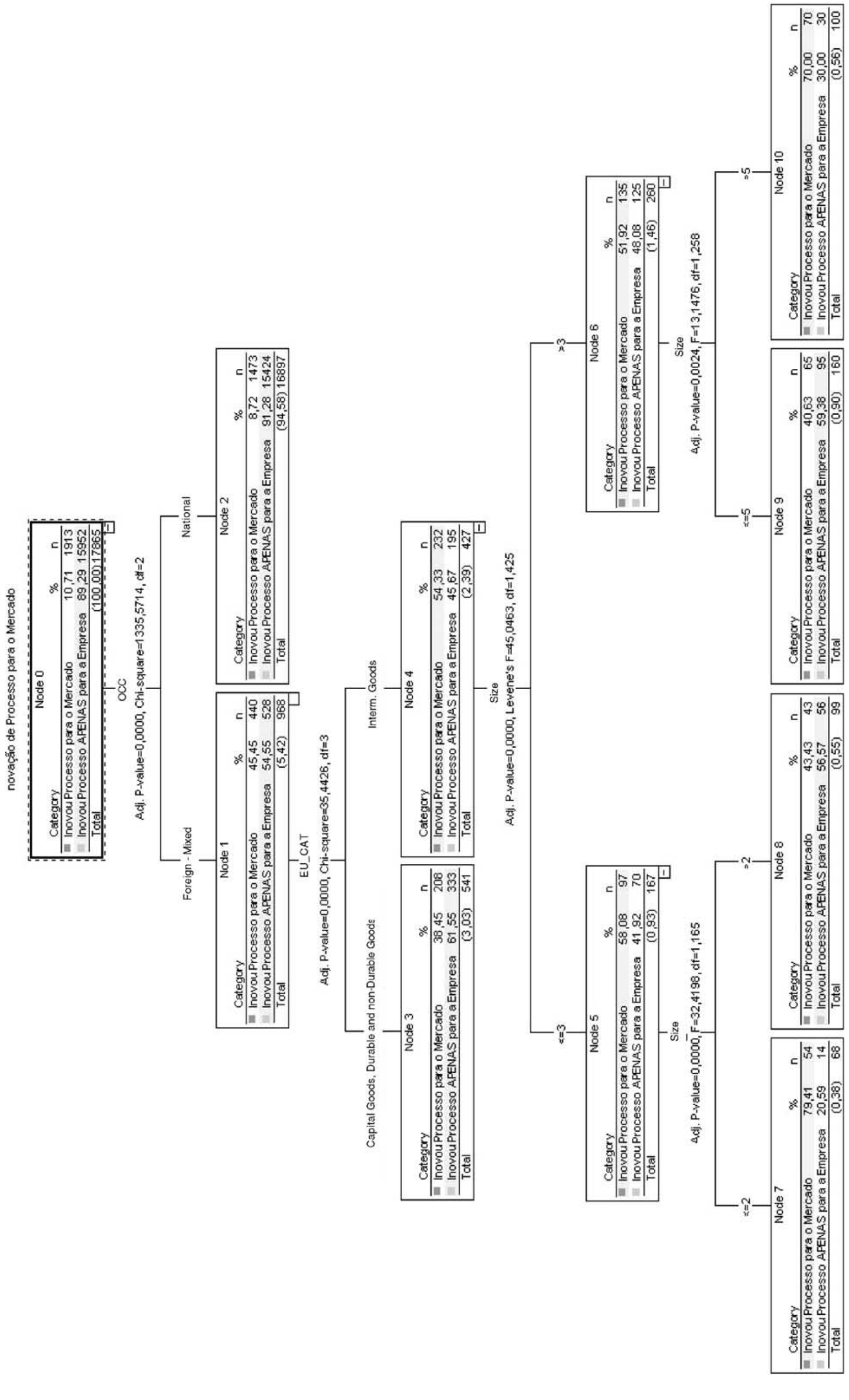
[18] Pinheiro and Moreira (2000), while estimating a model for the probability of a firm to export, found that the interaction between size and foreign capital origin has a negative effect on this probability. This means that the probability of a foreign firm to export is less sensitive to the increase in size of this firm than in the case of a Brazilian firm.

[19] Inside the trees “Inovou Processo para o Mercado“means process innovation for market, and “Inovou Processo Apenas para Empresa” means process innovation only for firm.

[20] Similarly to the previous case, this error estimate is lower than the naive estimate of 0.5 and also slightly lower than the estimate that every firm is innovative for the firms only.



Tree 3. Process innovation—minimal risk—symmetric costs.



Tree 4. Process innovation—pruned tree—symmetric costs.

between the first and second nodes is related to firm size. Interestingly enough, the node 11, with a higher rate corresponds to firms with less than 50 employees, whereas the second node corresponds to firms with 500 or more employees. In other words, the firms that are process innovators for the market are at the end of the size ranges. The terminal node 16, with a third higher rate of innovators for the market is that corresponds to foreign firms with 500 or more employees which export continuously and do not manufacture intermediate goods. Taking pruned Tree 4 into consideration, we may observe that in general the categories that define innovators for the market in a stronger fashion are those of capital origin and sectoral distribution, according to the end-use category. Secondly, exporting orientation and firm size are also important. These results are confirmed by the estimates produced by the logit model, as can be checked by means of the marginal effects and odds ratios estimated by the logit model (Table A.2 in Appendix A).

The tree estimated with asymmetric costs, with double costs for the misclassification of innovators for the market as being innovators for the firm only, shows that Brazilian non-exporting firms controlled by industrial groups and with 49 or fewer employees may be also classified as process innovators for the market.[21] This tree also has a node which there is an above-average probability of a firm being a process innovator for the market if it is a Brazilian firm that exports continually and if it belongs to a business group.

4.2.2. Product innovation

The estimates of classification trees for the dependent variable *product innovation for the market* or *only for the firm* are shown next. Tables 9 and 10 show the statistical summaries of classification Trees 5 and 6,[22] with minimal risk and pruned, with symmetric classification costs.

Tree 5 shows the importance of firms being exporters so they can be classified as product innovators for the market. The most homogeneous node for this class of firms is the number 13, which corresponds to that includes foreign firms that export continuously.

Table 9
Statistical summary of minimal risk tree—symmetric cost

Nodes	Frequency	Rate	Profit
13	556	4.5	0.65
20	63	0.5	0.65
17	63	0.5	0.52
8	228	1.8	0.51
16	95	0.8	0.49
14	85	0.7	0.49
9	2,928	23.6	0.34
6	4,062	32.7	0.24
19	93	0.7	0.11
18	72	0.6	0.07
12	4,171	33.6	0.06

Classification matrix

Predicted value	Observed value	
	Non-innovative	Innovative
Non-innovative	554	356
Innovative	2, 319	9,187
Risk	0.215448	

The second node in terms of percentage classification is the number 20, which includes Brazilian exporting firms belonging to sectors with medium and high technological opportunity, with 50–99 employees. In third place, we have the terminal node 17 for non-exporting firms that manufacture consumer goods and are controlled by some other firm. Tree 6 shows that for firms to be classified as product innovators for the market they should be exporters and have foreign or mixed capital. Again, the estimates of the *logit* model corroborate these results (Table A.3 in the Appendix A).

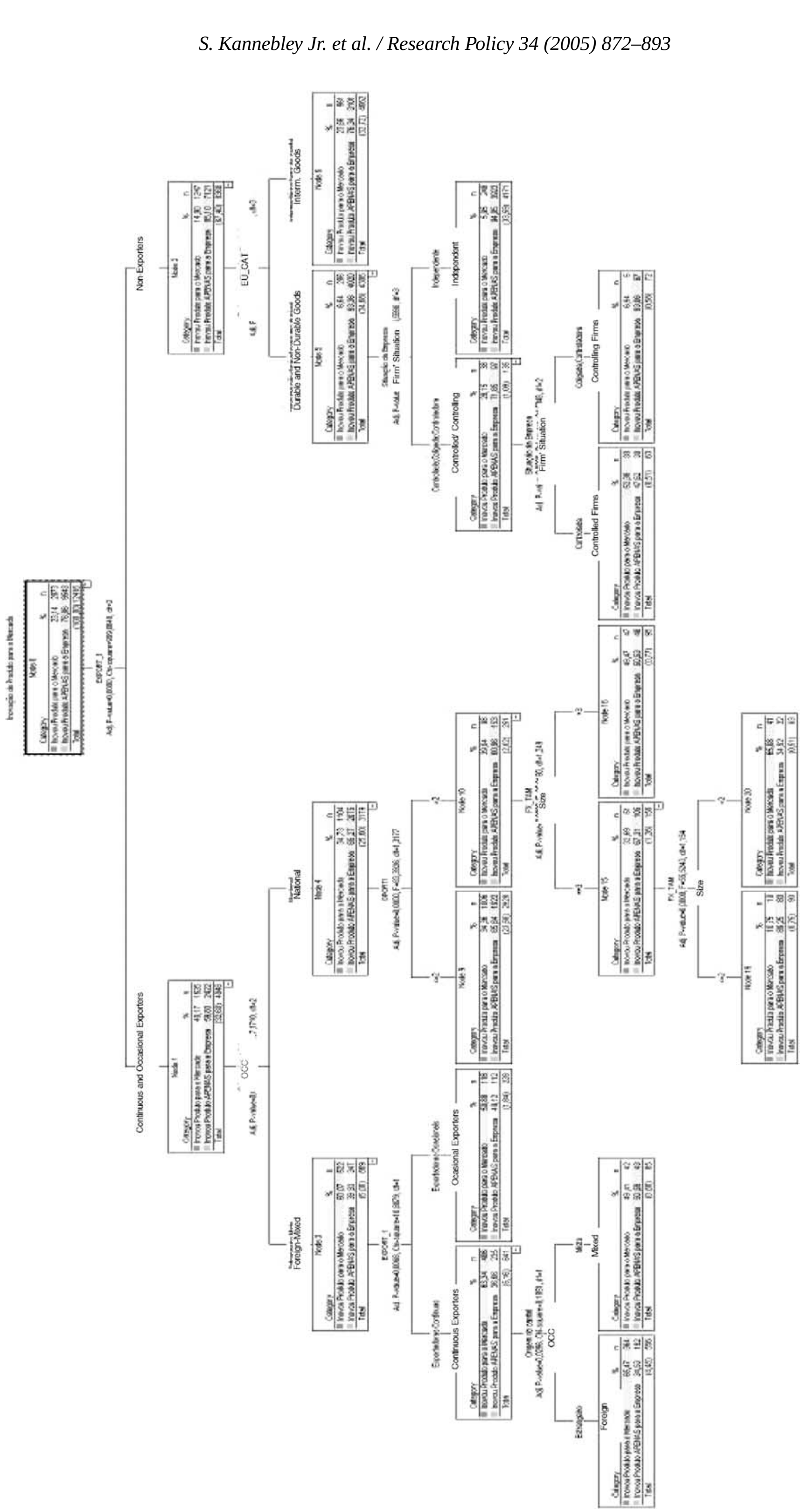
Table 10
Statistical summary of the pruned tree—symmetric cost

Nodes	Frequency	Rate	Profit
3	869	7.0	0.60
4	3,179	25.6	0.35
2	8,368	67.4	0.15

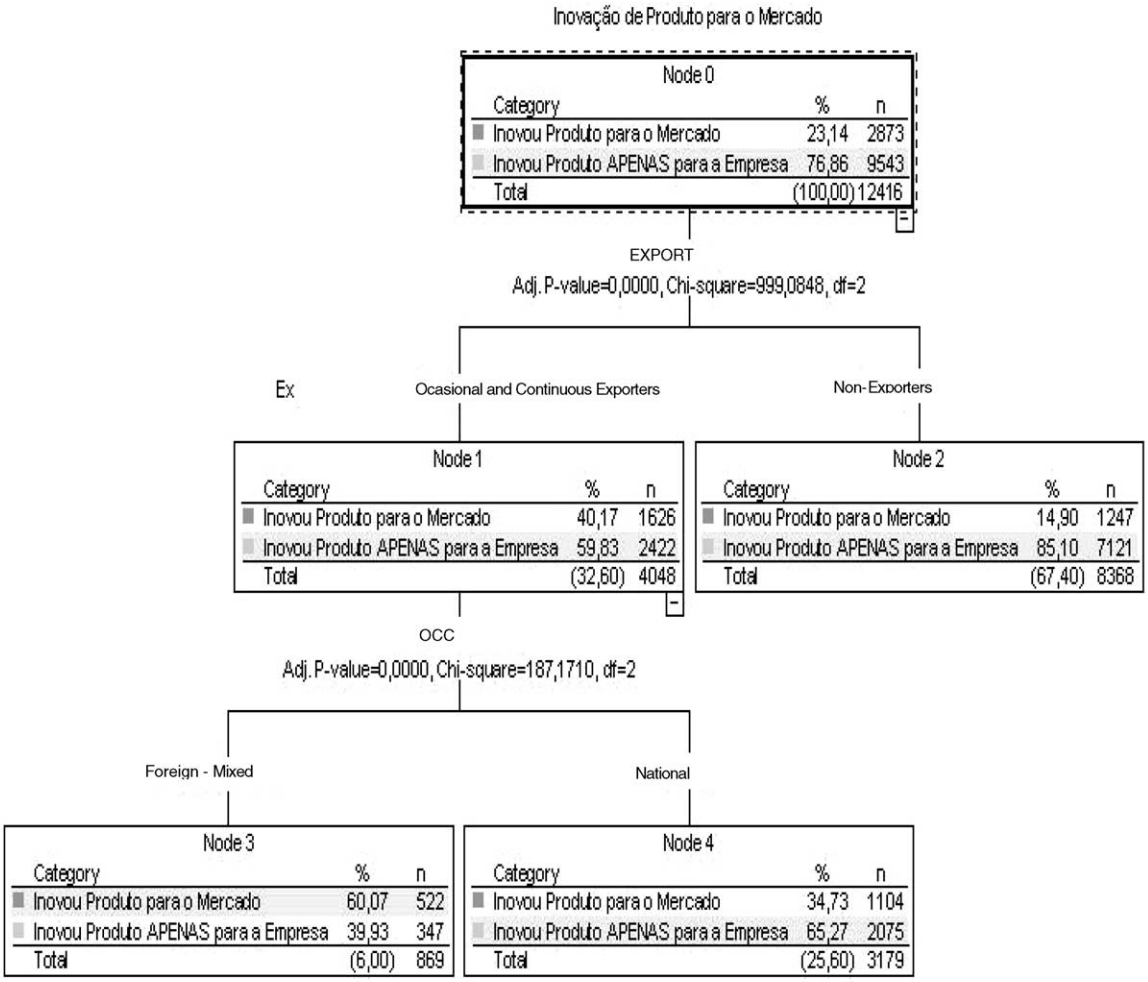
Classification matrix

Predicted value	Observed value	
	Non-innovative	Innovative
Non-innovative	522	347
Innovative	2, 351	9,196
Risk	0.2173	

[21] These results may be provided by the authors upon request.
[22] Inside the trees “Inovou Produto para o Mercado” means product innovation for market, and “Inovou Produto Apenas para Empresa” means product innovation only for firm.



Tree 5. Product innovation—minimal risk—symmetric costs.



Tree 6. Product innovation—pruned tree—symmetric costs.

In the tree estimated with asymmetric costs for the misclassification of product innovators for the market, some classifications are noteworthy. With regard to exporting firms with domestic capital, the fact of whether they belong to sectors with medium low, medium or high technological opportunities, or whether they have 500 or more employees and belong to sectors with low technological opportunity, is extremely important. As to non-exporting firms, those that manufacture intermediate or capital goods, operate in sectors with low and medium low technological opportunities and belong to business groups are more likely to be product innovators for the market. We should note that in the branch of non-exporting firms, regardless of the sector which they belong, a factor that increases the probability of the firm being an innovator for the market is related to whether they belong to some business group.

Again, for a clearer understanding of the results obtained for market innovation, it is important to contextualize the economic period in which these innovations took place. The trade liberalization of the Brazilian economy that began in the late 1980s led the Brazilian industry to adjust to international competition standards. This occurred in two different phases. The first one took place approximately between 1990 and 1993, when an essentially defensive industrial restructuring was implemented, whose focus was on attempting to increase labor productivity and to cut down costs.[23] Later on, with the macroeconomic stabilization of the economy, exchange rate appreciation and consolidation of trade liberalization, business strategies to respond to international competition were more aggressive and, in general, were targeted on increasing capital productivity and on launching new products.

It is in this context of the second phase of industrial restructuring that process innovations described in the study should be analyzed. The larger number of process and product innovations *only for the firm*, of Brazilian firms, reflects the search for modernization carried out by firms so as maintain their competitive edge in the market in response to the competitive pressure imposed by imported products.

Some considerations should also be made about foreign firms. In the trade regime that preceded liberalization, which strongly protected the domestic market, foreign firms had few incentives to seek efficiency and qualify as best international practices, offering technologically obsolete products in relation to those offered by the firms' headquarters or other branches in countries where economies were open to international trade. By exposing these firms installed in Brazil to international competition, trade liberalization encouraged them to recover their competitive edge, also redefining their form of insertion in domestic and international markets. Easier access to technology and financing allowed for a more intense process of competition recovery in comparison with Brazilian firms.[24]

Based on these arguments, one can understand the prevalence of foreign or mixed-capital firms, in interaction with the exporting orientation of the firms, in the results of innovative firms for the market. In other words, these results reflect the recovery or reaffirmation of foreign firms in introducing innovations to the Brazilian market, especially in sectors that are scale or capital-intensive and in which these firms are more present.

5. Concluding remarks

The aim of the present paper was to outline a profile of Brazilian innovative firms. The analysis was based on microdata obtained from PINTEC-2000. Regression and classification trees were estimated, where dependent variables were binary variables for *innovation or no innovation or innovation only for the firm or for the market*.

Firstly, the analysis focused on general innovation, without distinguishing between the type of innovation (process and/or product) or the scope of the innovation (for the market or only for the firm). The results obtained showed that for general innovation exporting orientation is the major determinant of innovation. Subsequently, we have firm size, which has a positive relationship between the chances of innovation and firm size. Finally, in the aggregate analysis of innovation, special attention should be given to the foreign or mixed capital origin and inter-industry differences as these variables may aid in the classification of innovative firms.

Later on, we selected the set of innovative firms and then we analyzed process and product innovations separately. For each of these subsets, we identified whether the firms introduced new processes or products at the market level or only at the firm level. In process innovation for the market, foreign or mixed capital origin and sectoral distribution were the main

[23] This period was marked by reduction in tariffs and elimination of non-tariff barriers to imports. At the beginning, the economy was in a recession; therefore, the business strategy was to lay off employees, shut down facilities, increase the efficiency of the productive process by way of the introduction of new management practices—organizational innovations, such as *Just in Time*, and improvement of quality systems, such as *Total Quality Management*, outsourcing of activities and qualification of production (focus on core business), combined with an increase in the import of inputs and parts. Moreover, fierce competition encouraged the geographical decentralization of industry, i.e., in order to adapt to high competition, firms sought to set up in regions that offered inexpensive production factors or more appealing to fiscal incentives.

[24] This does not necessarily mean that branches of multinational firms installed in Brazil began to carry out research, development and engineering of process and product in order to develop local competences. However, it was possible to observe a larger technological effort by foreign firms for the year 2000, according to PINTEC, regarding the intensity of R&D. Whereas for Brazilian firms the ratio between expenditure with R&D and the revenue amounted to 0.56%, it reached 0.78% for foreign firms. This information can be better qualified, by noting, in the first place, that net revenues of foreign firms are nearly two times higher than those of Brazilian firms, and that the distribution of R&D intensities relative to firm size is less homogeneous in case of foreign firms, compared to Brazilian firms, with a larger concentration of R&D intensities in large firm sizes.

determinants of process innovation for the market. For this type of innovation, firm size, although significant, did not show a monotonic relationship with process innovation for the market.

In case of product innovation for the market, exporting orientation and foreign and mixed capital origin are the major variables. Even though firm size and the fact of whether firms belong to a business group has been important for the estimation of minimal risk trees, the reduction process showed that the discriminatory capacity of these variables is low.

Differently from what is presented by the empirical literature on this issue, firm size was not the main discriminatory variable for innovative activity in any of the analyzed forms. The evidence obtained in the present paper highlights the importance of two characteristics: exporting orientation and foreign or mixed capital origin. Given the sector effects, it was possible to show that firms with these characteristics are responsible for technological improvement in Brazil. This does not mean that firm size is not relevant in the determination of innovative activity, but this shows that it is a complement to the other two characteristics mentioned above.

To conclude, it is important that sectoral differences in Brazilian industries be taken into consideration. There are sectors, such as the manufacture of basic electronic equipment, pharmaceuticals, and food, in which very small, small and medium-sized firms had an above-average performance. On the other hand, in sectors such as steel products, tobacco, paper pulp, medical and hospital equipment, most of the innovations for the market were attained by large firms. Thus, we should clarify that the relationship between firm size and innovation for the market cannot be generalized for the industry as a whole. Firm size, as presented in the analysis of the dependent variable *innovation* is relevant in defining the probability of a firm being an innovator, but not necessarily in defining that the firm should be innovative for the market.

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Appendix A

The logit model has the same purpose of the classification and regression tree, as it seeks to explain the occurrence or not of a certain event. Thus, similarly to trees, this model was used to estimate the probability of a firm to innovate or not, or to innovate in process, or product, only for the firm or for the market. This probability can be represented as follows:

$$\text{Prob}(Y_i|X_i) = E(Y_i\,|X_i) = \frac{e^Z}{1+e^Z}$$

where Y_i is the discrete random variable equal to 1 if the ith firm introduces a specific innovative activity, and equal to 0, otherwise. The set of dependent and explanatory variables is the one shown in Tables 1 and 2, respectively. However, for the variable that represents firm size, the logarithm of the total number of employees, Ln_Employee, was used instead of the categorical variable “SIZE”. The fixed sectoral effects are captured by dummy variables corresponding to each sector. Let X_i be the value of the ith explanatory variable for the ith firm and β_j a parameter to be estimated, then

$$Z = \beta_0 + \sum_{j=1}^{J} \beta_j X_{ij}.$$

The results of the logit model can be associated with those presented by regression and classification trees by calculating marginal effects and the odds ratios of explanatory variables on conditional expectation. These measures correspond to the hierarchical order of explanatory variables presented by the regression tree, since they represent the impact of the variable *size*, or the presence or not, of another characteristic of the firm on the probability to innovate.[25]

[25] Formally, the calculation of marginal effects and odds ratios represented respectively by the following expressions: $\frac{\partial(E(Y_i))}{\partial X_j} = F(\beta' X)(1 - F(\beta' X))\beta_j = f((\beta' X)\beta_j \text{e}\frac{\text{Prob}(Y_i=1)}{\text{Prob}(Y_i=0)} = \text{e}^Z$. The odds

Table A.1
Impact of firm's characteristics on the probability of a firm being innovative—general industry

Dependent variable = probability of a firm being innovative[a]

Independent variables		Coefficients	Wald	Odds ratio	Marginal effect[b]
Labor	Ln_Employee	0.418	1692.08	1.520	0.0886
Reference	Foreign	0.274	20.690	1.315	0.0579
Domestic	Mixed	0.171	2.655	1.186	0.0361
Reference	Exports occasionally	0.396	157.196	1.487	0.0839
Does not export	Exports continually	0.507	236.897	1.659	0.1072
Reference	Controlling	0.359	9.931	1.432	0.0761
Independent	Controlled	0.043	0.519	1.044	0.0092
	Related	0.237	6.777	1.268	0.0502
Constant		−2.438	1961.62	0.087	−0.5163

[a] Estimates are controlled by sector effects.
[b] Marginal effects were calculated for the firm with medium technological opportunity.

Table A.2
Impact of firm's characteristics on the probability of a firm being a process innovator for the market—general industry

Dependent variable = probability of a firm being a process innovator for the market[a]

Independent variables		Coefficients	Wald	Odds ratio	Marginal effect[b]
Labor	Ln_Employee	0.280	135.275	1.323	0.061
Reference	Foreign	0.913	105.732	2.493	0.198
Domestic	Mixed	0.593	10.966	1.810	0.129
Reference	Exports occasionally	0.899	141.019	2.458	0.195
Does not export	Exports continually	0.800	106.566	2.225	0.173
Reference	Controlling	0.601	13.105	1.824	0.130
Independent	Controlled	0.607	40.207	1.834	0.131
	Related	−0.244	1.695	0.784	−0.053
Constant		−3.648	600.931	0.026	−0.791

[a] Estimates are controlled by sector effects.
[b] Marginal effects were calculated for the firm with medium technological opportunity.

As shown in Tables A.1–A.3, marginal effects and the odds ratios confirm the hierarchical classifications proposed by the classification and regression trees presented above. In Table A.1, in which the model for general innovation is outlined, continuous exporting orientation, followed by firm size, and occasional exporting orientation, are the three major characteristics that explain the probability of the firm to innovate. In Table A.2, foreign capital origin, followed by occasional exporting orientation and continuous exporting orientation were the three major characteristics that explain the probability of the firm to innovate in process for the market. In Table A.3, continuous exporting orientation, followed by occasional exporting orientation and mixed capital origin are the three major characteristics that explain the probability of the firm to innovate in product for the market.

ratios can be calculated for the *innovation* event considering a mean value for the explanatory variables, or the presence or not of a characteristic of the firms expressed by categorical variables. The interpretation in case of continuous variables is not clear, and therefore it is recommended that the marginal effects be calculated using mean or median values of explanatory variables. Odds ratios greater than one indicate enhanced probability to innovate considering the variable in particular. The opposite applies if the odds ratio is smaller than one. For further details, see Greene (1997), among others.

Table A.3
Impact of firm's characteristics on the probability of a firm being a product innovator for the market—general industry

Dependent variable = probability of a firm being a product innovator for the market[a]

Independent variables		Coefficients	Wald	Odds ratio	Marginal effect[b]
Labor	Ln_Employee	0.195	72.127	1.216	0.042
Reference	Foreign	0.520	36.467	1.682	0.112
Domestic	Mixed	0.576	13.516	1.780	0.124
Reference	Exports occasionally	0.662	92.555	1.939	0.143
Does not export	Exports continually	0.698	104.400	2.009	0.150
Reference	Controlling	0.551	11.358	1.735	0.119
Independent	Controlled	0.515	30.612	1.674	0.111
	Related	−0.204	1.490	0.815	−0.044
Constant		−2.952	395.836	0.052	−0.637

[a] Estimates are controlled by sector effects.
[b] Marginal effects were calculated for the firm with medium technological opportunity.

Appendix B

Sectoral distribution according to technological opportunity

Low opportunity
- Extraction industries
- Manufacture of food products and beverages
- Manufacture of tobacco products
- Manufacture of textiles
- Clothing items and accessories
- Leather processing and manufacture of leather products, travel goods and shoes
- Manufacture of wooden products
- Manufacture of pulp, paper and paper products
- Editing, printing and recording
- Petroleum coking, oil refining, nuclear fuel and alcohol production
- Manufacture of rubber and plastic products
- Manufacture of nonmetallic mineral products
- Basic metallurgy—excluding steel products
- Manufacture of metal products
- Recycling

Medium-low opportunity
- Nonferrous metal processing and melting
- Oil refining
- Manufacture of chemicals
- Manufacture of pharmaceuticals
- Steel products
- Manufacture of machinery and equipment
- Manufacture of machines, electric apparatuses and material
- Manufacture of basic electronic equipment

Medium opportunity
- Manufacture of communications devices and equipment—excluding manufacture of basic electronic equipment

Appendix B (*Continued*)

- Manufacture of medical and hospital tools, precision and optical instruments, industrial automation equipment, timers and watches/clocks
- Manufacture and assembly of motor vehicles, semi-trailers and bodies—excluding manufacture of parts and accessories for motor vehicles

High opportunity
- Manaufacture of office equipment and computers
- Manufacture of other transportation equipment

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