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ARTICLE

Decisive Factors of Eco-innovation in the Brazilian Electronic Complex*

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ABSTRACT

Eco-innovation is an important concept, seeing as a strategy of transition to Green Economy, Circular Economy and Industrial Ecosystems. Internationally, many studies are being carried out searching for their determinants, but in low-income countries they are rare. The objective of this article is to investigate the determinants factors of Eco-innovations in the companies of the Brazilian electronic complex members of the Brazilian Association of the Electrical and Electronics Industry (ABINEE), through field research and descriptive statistical analysis

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and estimation of the binomial and multinomial Logit models. A sample of 48 companies was obtained which resulted from the models related to 1%. The results pointed out that the market, and not environmental regulation, has been the main determining factor of Eco-innovations since other variables need to be incorporated into the model (effective implementation of the regulation, institutional training and rigor/*enforcement* and type of environmental impact). Product Eco-innovation depends on the market, while those of process depend on regulations; more innovative firms are also eco-innovators and the size of the company matters, but not the source of the capital, as the practice of the branch is often not linked to the head office.

Keywords | Eco-innovation; Electronic complex; Determinants

1. Introduction

Great environmental challenges, germinated throughout history, have taken proportions that evidences the limits of support of the planet, such as the population growth and changes in the consumption pattern, climate changes, the disappearance of biological varieties, scarcity of resources and energy, among others (OCIEPA-KUBICKA; PACHURA, 2017; SERENELLA *et al.*, 2017).

Eco-innovations can be a strategy to achieve the Green Economy, since it aims, under political incentives, to reconcile economic progress with environmental preservation (MOURA, 2016). Eco-innovation is also a way of moving towards the Circular Economy, because, in this concept, the product, at the end of its life cycle, can be reused repeatedly and create more value. It would allow combining the challenge of achieving global sustainability with technological and organizational development and the managerial challenge of reducing the environmental impact of consumption and production actions (SMOL; KULCZYCKA; AVDIUSHCHENKO, 2017; GENTE; PATTANARO, 2019). Considering the need to rethink economic activities as a subsystem of the natural ecosystem, in which inputs (renewable) and waste material (reusable) can be reused in a closed cycle, these Industrial Ecosystems can become eco-innovative strategies (CRUZ; HOFF, 2018). Academically, publications of scientific articles, on bases such as *ISI Web Knowledge* on Eco-innovation, have been increasing since 1994, and have been intensified since 2008 (BOSSLE *et al.*, 2016).

Thus, many international studies have investigated the determinants of Eco-innovations, especially in Europe, based, mostly, on data provided by the *Community Innovation Survey* (CIS), which provide information on Eco-innovation, such as company profiles, determining factors, and their relationship with types of Eco-innovation and types of environmental impacts (CHIARVESIO; DE MARCHI; DI MARIA, 2015; BORGHESI; CAINELLI; MAZZANTI, 2015; HORBACH; OLTRA; BELIN, 2013; HORBACH; RAMMER; RENNINGS, 2012; HORBACH, 2016; CAINELLI; D 'AMATO; MAZZANTI, 2015).

Studies on developing countries are scarce, as well as detailed econometric analyses on certain sectors and regions (DEL RIO; PEŇASCO; ROMERO-JORDAN, 2016). In Brazil, some authors have been working on the theme recently, exploring, above all, the profile of eco-innovative companies, through data provided by the Survey of Innovation (PINTEC), of the Brazilian Institute of Geography and Statistics (IBGE) (QUEIROZ; PODCAMENI, 2014; HOFF; AVELLAR; ANDRADE, 2016). Others have gone further by establishing an overview of the practice of Eco-innovations in the Brazilian process industry and identifying their characteristics and determinants, such as regulation and market factors (MOURA, 2016). In sectoral terms, research has shown that the number of companies in the electronic complex that perform Eco-innovations has increased (MORO, 2014).

However, the main source of data for Eco-innovations is PINTEC, which deals only with innovations that have resulted in reduced consumption of water, energy, materials and environmental management systems, and considers the role of regulations in general (without specifying whether it is environmental or not).

The objective of this article is to contribute to such a discussion, investigating the determining factors of Eco-innovations in the companies of the Brazilian electronic complex related to the Brazilian Electrical and Electronics Industry Association (ABINEE). Such selection is due to the representativeness of the electronic complex in the Brazilian Gross Domestic Product (GDP), for its innovative profile and the environmental impacts generated after the product's life cycle. Therefore, besides the literature review (second section), this study was carried out through field research in ABINEE companies, whose data and results were treated and discussed through descriptive statistical analysis and estimation of the binomial and multinomial Logit models (third and fourth sections). In the last section, the conclusions of the work are presented.

2. Decisive Factors of Eco-innovation: literature review

Eco-innovation is a recent concept that emerged in the 1990s (KEMP, 2010). There is no consensual definition of the term, but the most used in international literature are those of Kemp and Pearson (2008) and OECD (2009 a and b) (BOSSLE *et al.*, 2016).

Kemp and Pearson (2008, p. 7), based on the OECD's innovation name (2005)[1], define Eco-innovation as:

> *[...] the production, application or use of a commodity, service, production process, organizational structure or management or business methods that are new to the firm (that developed or adopted it) and that results, through its life cycle, on the reducing of environmental risk, pollution, and other negative impacts of resource use (including energy use) compared to relevant alternatives.*

1 Innovation is the implementation of new or improved products (commodities or services), processes, methods of marketing, or organization (OECD, 2005).

This definition, besides considering the entire life cycle of the product including post-consumption, for Horbach, Rammer and Rennings (2012), is extensive and has three characteristics: 1) it is based on a subjective view, as it is about novelty for the firm and is in line with the Oslo Manual; 2) considers implemented innovations aimed at environmental results and 3) relates environmental impact to the state of the art, by comparing relevant alternatives.

For OECD, Eco-innovation is an innovation not only in products but also in organizational processes and methods, which brings benefits to the environment or at least reduces environmental impacts (OECD, 2009a), whether intentional or not. Eco-innovations can be analyzed in three dimensions (OECD, 2009b):

- objectives: focus on Eco-innovations (product, process, methods, organizational changes), among others;
- mechanisms: how the changes that generate Eco-innovations are introduced (modifications, *redesign*, alternatives, and creation);
- impacts: effect of Eco-innovations on the environment.

Comparing the two definitions, both are aligned with the Oslo Manual and are not restricted to the intention of obtaining environmental results. However, product and process Eco-innovations for OECD (2009b) are related to technological changes, while for Kemp and Pearson (2008) not exclusively, expanding the concept. Kemp and Pearson (2008) also insert the notion of the product's life cycle, which is fundamental for the study of electronics.

Thus, the definition of Eco-innovation by Kemp and Pearson (2008) stands out for incorporating the analysis of the product's life cycle, giving more precision to the concept. This is because it allows considering the environmental effects from the product's composition to its final disposal after use. Also, among 22 studies, this one by Kemp and Pearson is the only one that covers all the main aspects of Eco-innovation: term, focus on the result (not on the intention), scope (reduction or prevention of environmental impact), complies with the Oslo Manual (in its third edition) and incorporates the notion of the product's life cycle (KOELLER *et al.*, 2020).

When it comes to the approach of the determinants of Eco-innovation, there are no conceptual differences between the authors, only small variations in the way of classifying the factors, as well as in the methodology employed (HORBACH; RAMMER; RENNINGS, 2012; BOSSLE *et al.*, 2016; ALOISE; NODARI; DORION, 2016).

Environmental regulation is recognized in the literature as the main determining factor of Eco-innovation since the formulation of the Porter Hypothesis, according to which companies, through pressure to correct environmental damage, undertake innovations that will balance their compliance costs, generating double benefits, economic and environmental (PORTER; VAN DER LINDE, 1995; HORBACH; RAMMER; RENNINGS, 2012; WONG, 2013). Regulation is necessary to direct Eco-innovation, because, unlike other innovations, firms are not able to recognize its potential in cost savings, such as energy consumption and use of materials (HORBACH; RAMMER; RENNINGS, 2012).

Despite its importance, to the authors, Eco-innovations do not constitute a systematic response to regulation. In reality, they alert to other factors related to the market and the technological capacity of the firms.

Rennings (2000) built a hybrid approach from the economy of innovation and the environmental economy. For the author, Eco-innovations face a type of double externality, due to the spillover effect resulting from the innovation process and the reduction of environmental externality caused by the new product or process. Thus, technological capacity and demand alone cannot trigger Eco-innovations, which requires regulatory support. As a result, Eco-innovation's regulatory determinants became known as regulatory push/pull effects. However, environmental regulation, exclusively, does not provide permanent incentives to maintain Eco-innovation, so that actions aimed at reducing emissions disappear once the compliance is fulfilled.

Rennings (2000) classified the determinants of Eco-innovations into three groups:

- technology push: such as material and energy efficiency and product quality;
- market pull: such as market share, competition, the conquest of new markets, the image and demand of consumers;
- regulatory push/pull effects: such as health and safety laws and regulations.
- Similarly, Horbach, Rammer and Rennings (2012) presented four sets of factors:
- regulation, whether existing or announced;
- factors pulled by the market, which refer to the benefits perceived by the consumer;
- factors pushed by technology, such as innovative activities, Research and Development (R&D), and organizational innovations;
- factors specific to firms, such as the presence of knowledge transfer mechanisms, involvement in cooperation networks, and environmental skills.

Horbach, Oltra and Belin (2013) and Horbach (2016) detailed the factors and included other types of instruments and political elements, presenting the determinants in another way:

- on the supply side: technological capabilities, which involve internal (R&D) and external (cooperation networks and research institutes) knowledge bases, resources (physical, human, financial, and organizational), appropriability (patents), and market characteristics;
- on the demand side: environmental awareness, consumer preference for environmentally friendly products, seeking to increase market share or penetrate new segments;
- regulation and political determinants: environmental policy (regulation and incentive instruments), institutional infrastructure, and regulatory design (rigor, flexibility, and adaptation time).

Bossle *et al.* (2016), through bibliographic review, concluded that the determining factors of Eco-innovations can be presented to the firms as external (regulatory pressure, normative pressure, and cooperation with external actors) and internal (technological and organizational efficiency, environmental management capacity, and human resources).

Some authors suggest the inclusion of control variables, such as the size of the firm, the source of capital, and the type of department (BOSSLE *et al.*, 2016; WONG, 2013; CLEFF; RENNINGS, 1999). Empirical evidence allowed to highlight the effect of each determinant on Eco-innovations and suggest the discussion of these complementary variables.

For Kemp (2010), the effects of environmental policy instruments depend on how they are used, so that environmental regulations tend to generate radical innovations, while rates and the emissions trading are more flexible and ineffective from the environmental point of view.

Cleff and Rennings (1999) observed that the majority of innovative firms in Germany were eco-innovators, in particular, the large ones. Process Eco-innovations were determined by regulation, while product Eco-innovations were determined by the market. This can be explained by the fact that process Eco-innovations provide low benefits to the consumer, while product innovations add.

Several studies carried out for Europe were supported by CIS. For Horbach, Rammer, and Rennings (2012), regulation had a strong influence on Eco-innovations, followed by cost savings, while subsidies were irrelevant. Thus, as already noted, regulation generated process innovations and cost savings, which is a market factor, were predominant for the development of cleaner technologies.

Horbach, Oltra and Belin (2013) compared the determinants of Eco-innovation in France and Germany, through an econometric study. The results were similar to those of the previous study for these countries, with the addition of two aspects: expenses with internal R&D proved irrelevant, but external sources of knowledge, such as cooperative relations with Research Institutes, were essential for Eco-innovations.

Horbach (2016), reflecting on the different levels of development between the countries of Europe, compared the determinants of Eco-innovation between countries in the West and the East. In general terms, it was observed, again, that the regulation generated process Eco-innovations, while the demand determined product Eco-innovations. Regulatory measures were noticeable in Eastern Europe due to the high intensity of pollution during the production process, pointing to a regulatory deficit in these countries. Technology transfer and the importance of government subsidies were also observed.

In Brazil, there are a few studies on Eco-innovation. For Lustosa (2002, 2010), internationalized companies showed greater environmental concerns, either due to pressure from the matrix or the foreign market; Larger companies believe that the environment influences their competitiveness and companies that invest in R&D and innovate are better able to adopt Eco-innovations.

Other studies based on PINTEC (several years) appear to indicate similar results. Queiroz and Podcameni (2014) noticed that the size of the firm and the source of capital, as well as factors associated with technological training, are important for the introduction of Eco-innovations. For Hoff, Avellar and Andrade (2016), any type of innovative activity, even with low R&D expenditure, is important for the realization of Eco-innovations.

As for the few studies on the determining factors, also from IBGE (2016), Moura (2016) found that the eco-innovative companies in the Brazilian process industry are large, with national capital, are not part of a specific group, and are not exporters. The main influence factor of Eco-innovation is related more to the innovative result (search for new markets, improvement of quality and image, cost reduction) than to regulation.

Likewise, Carvalho, Savaget and Arruda (2013), through field research performed with 98 Brazilian companies, showed that the main determinants of Eco-innovation refer to the market (creating new markets, reducing costs, and improving image) and R&D expenditure. Eco-innovative companies guided by environmental regulation tend to create incremental process and organizational innovations.

In the electronics sector, Moro (2014), using IBGE (2016), found that most companies in the sector are eco-innovators; of these, the majority are large, with foreign capital and have low levels of cooperation. The main determinants were regulation, R&D expenditure and acquisition of software, and machinery and equipment, however, at PINTEC it is not clear which regulation is and what other elements should be considered.

Chart 1 presents the main works carried out on the determinants of Eco-innovation.

CHART 1
Summary of the main researches on the determinants of Eco-innovation

Author(s)	Determinant Factors of Eco-innovation	Additional Determining Factors in Low Income Countries/Brazil	Relationship between factors and type of innovation
Rennings (2000)	Pushed by technology, pulled by the market, and pulled/pushed by regulation	No	No
Horbach, Rammer and Rennings (2012)	Regulation (existing or announced), factors pulled by the market, pushed by technology and organizational innovations, and factors specific to firms.	No	Regulation generates Eco-innovation and process, and market with cleaner technologies
Cleff and Rennings (1999)	Pushed by technology, pulled by the market, and pulled/pushed by regulation	No	Regulation generates Eco-innovation and process, and product market
Bossle *et al.* (2016)	External (regulation and cooperation) and internal (technology, organization, and management) to firms	No	No
Horbach, Oltra and Belin (2013)	Supply side (technology), demand side (market) and regulation side and political determinants	No	Regulation generates Eco-innovation and process, and product market
Horbach (2016)	Supply side (technology), demand side (market) and regulation side and political determinants	Yes (Eastern Europe): external technology and government incentives	No

(continued)

CHART 1
Summary of the main researches on the determinants of Eco-innovation

(continued)

Author(s)	Determinant Factors of Eco-innovation	Additional Determining Factors in Low Income Countries/ Brazil	Relationship between factors and type of innovation
Lustosa (2002, 2010)	Regulation, innovative activities, the source of capital, destination market, and size of the firm	Yes: the source of capital, destination market, and size of the firm	No
Queiroz and Podcameni (2014)	Regulation, innovative activities, the source of capital, destination market, and size of the firm	Yes: the source of capital, destination market, and size of the firm	No
Moura (2016)	Regulation, market, innovative activities, the source of capital, destination market, and size of the firm	Yes: the source of capital, destination market, and size of the firm	No
Carvalho, Savaget and Arruda (2013)	Market, regulation, innovative activities (R&D expenditure)	Yes: the source of capital, destination market, and size of the firm	Regulation generates incremental process and organizational Eco-innovation
Moro (2014)	Regulation, market, innovative activities and R&D expenditure, the source of capital	Yes: the source of capital and size of the company; electronic sector	No

Source: Own elaboration

Thus, the most frequent notes in the literature, whether theoretical or empirical, concerning the determining factors of Eco-innovations (and their implications especially for developing countries, such as Brazil), allow us to formulate four Hypotheses:

- H1: environmental regulation is the main driver of Eco-innovation;
- H2: environmental regulation has a strong influence on process Eco-innovation, while the market has a strong influence on product Eco-innovation;
- H3: innovative firms are also Eco-innovators; and
- H4: the size of the company and the source of the capital matter for the development of the Eco-innovation.

3. Methodology

According to the Brazilian Association of the Electrical and Electronics Industry (ABINEE, 2019), the electrical and electronic equipment sector comprises the segments of electrical and electronic components, mobile communication devices, telecommunications, electronics manufacturing services, information technology, electronic security equipment, electrical and electronic home appliances, and industrial automation. The sector's sales, regarding the GDP and the Industrial GDP, were around 2.1% and 9.8% respectively in the last years (2016-2018). Its trade balance has been in deficit, with Latin American countries as the main destination for exports and Asian countries as the source of imports.

This sector has relevant technological and environmental characteristics regarding the study of Eco-innovation that justify its choice. It is considered one of the most innovative sectors with the highest technological content in Brazil, according to PINTEC 2014, carried out by IBGE (2016). In addition to the automotive sector, the segments that had the highest innovation rates, between 2012 and 2014, were: computer equipment and peripherals (74.8%); manufacture of communication equipment (73.7%); manufacture of other electronic and optical products (73.6%) and manufacture of electromedical and electrotherapeutic devices and irradiation equipment (72.7%).

According to international studies (LOW; YEATS, 1992; MANI; WHEELER, 1998; HETTIGE *et al.*, 1995), the sector producing electrical and electronic equipment is classified as clean, according to the pollutant emission criterion during the production process, by presenting lower expenses with reduction and control of pollutants than other sectors (chemical, petrochemical, oil and, cellulose and paper). However, according to the criteria of environmental pressure resulting from the final consumption of the product, considering the entire life cycle of the product, the electronic sector stands out for its great intensity in the use of energy during consumption (UNEP, 2010) and the increasing generation of post-consumption dangerous waste (BALDÉ *et al.*, 2017). In 2017, 44.7 million tons of electronic waste were generated, which is equivalent to 6.1 kilos per inhabitant[2]. Brazil is the second-largest producer of electronic waste in the Americas. As electronic equipment contains materials such as cadmium, chromium, mercury, lead, among others, its

2 Waste or E-waste is understood as a range of products with electrical circuits or components with energy source or battery such as refrigerators, freezers, screens, lamps, washers, microwaves, printers, cell phones, computers (BALDÉ *et al.*, 2017).

improper disposal can cause irreversible damage to human, plant, and environmental health (BALDÉ *et al.*, 2017).

As for the form of conducting the field research, a questionnaire was prepared, and previously tested by ABINEE specialists, covering: the characteristics of the companies (size, the source of capital, destination market, segment), the main types (product, process), determinant factors of Eco-innovation and innovative activities. The definition of Eco-innovation used is that of Kemp and Pearson (2008), the determining factors were those raised by the literature (hypotheses) and the types of Eco-innovation, as well as innovative activities, in line with those of the Oslo Manual (OECD)/PINTEC (Brazil) and Kemp and Pearson (2008).[3]

Then, the questionnaires were sent to executive directors of 411 companies linked to ABINNE, through the Technology and Industrial Policy Manager at ABINEE, Israel M. Guratti, between July 2016 and April 2017, by electronic mail. The name of the company was kept confidential to give freedom and avoid bias in the responses. The executive directors forwarded it to specialists in the field in their company so that the questionnaires were answered, among others, by quality and environmental managers, administrative or R&D. Thus, this survey, inspired by PINTEC, reflects the respondents' perception of Eco-innovations.

Of the 411 member companies of ABINNE, which constitute the population of this study, 48 respondents were obtained, representing about 12% of the total, being characterized as a study whose population is finite.

The traditional formulas of variance must undergo a correction in this type of study. Specifically, the proportion variance will be given by:

$$var(\hat{p}) = \frac{\hat{p}(1-\hat{p})}{n}\frac{N-n}{N-1} \,. \quad (1)$$

3 The questionnaire consisted of 16 closed-ended, multiple-choice questions, some with more than one option. Among the questions, based on the definition of Eco-innovation by Kemp and Pearson (2008) and PINTEC, there were groups with: characteristics of the companies (size, the source of capital, the segment of operation and destination market); realization of innovation and environmental innovation and its determinants; types of environmental innovation and effects. To test the hypotheses, besides the crossing with information about the characteristics of the companies, the following questions were asked: did your company undertook any type of technological innovation in the last five years? (new or improved product or process); Has your company undertook any technological innovations that have brought about environmental improvements in the last three years? The necessary R&D investments to undertake environmental innovations represented: less than 2.5% of total R&D investment; between 2.5% and 5% of total R&D expenditure; between 5% and 10% of total R&D expenditure or more than 10% of total R&D expenditure? If your company undertook any Environmental Innovation, what was it (new or improved product or process; new or improved organization; new or improved environmental management system; new plant; other)?; Reasons that led your company to undertake Environmental Innovations: market (customer, supplier, image, differentiate the product, conquer markets) requirements; the source of capital (matrix policy, comply with foreign environmental regulations), regulation (comply with the National Solid Waste Policy, comply with the National Climate Change Policy, or other national environmental regulation, meet requirements of the state environmental agency, environmental seal, pressure from environmental groups and associations and government incentives or participation in government environmental programs).

Anyway, although the sample represents 12% of the population (which is relevant), it is not representative for the results to be extrapolated[4]. However, the most important result of the work was to obtain estimates of the significant models at 1%. That is, even considering the small sample size, the study found evidence to statistically prove some hypotheses of the study, which suggests that in the population there could also be certain relationships. Also, field researches that seek primary data from companies are unlikely to result in statistically representative samples, but they bring new elements and variables that are not available in national databases. Even though the answers were provided by the only 48 companies that answered the questionnaire, the information gathered represents a good picture of the sector.

After this period, the answers to the questionnaires were tabulated and the hypotheses were tested using descriptive statistics and estimates from the Logit binomial or multinomial models, as appropriate. If the dependent variable can be the result of multiple responses, numbered from 0 to *k* - 1, *k* - 1 coefficient vectors βj were estimated, representing the probability of choosing the alternatives *j* = 1, 2, ..., *k* - 1, probability that was calculated by the logistic function, that is:

$$P(Y_i = j) = \frac{e^{\beta_j' X_i}}{1+\sum_{j=1}^{k-1} e^{\beta_j' X_i}} \tag{1}$$

Being the choice of the answer j = 0 given by the difference between 1 and the sum of the others, so that:

$$P(Y_i = 0) = \frac{1}{1 + \sum_{j=1}^{k-1} e^{\beta_j' X_i}} \tag{2}$$

In this equation, X_i is the vector with the model's variables.

These coefficients were estimated by maximum probability.

The binomial logit can be considered a particular case of the multinomial, in which there are only two choices, *Y* = 0 or 1, in such a way that only one vector is necessary to estimate the probability of choosing one of the alternatives.

$$P(Y_i = 1) = \frac{e^{\beta' X_i}}{1 + e^{\beta' X_i}} \tag{3}$$

4 This sample was obtained looking for the highest possible statistical precision within the constraints of time and resources.

$$P(Y_i = 0) = \frac{1}{1 + e^{\beta' X_i}} \quad (4)$$

4.Results and discussion

As shown in Chart 2, almost half of the companies in the sample were controlled by national capital and half by foreign capital or branches in the United States of America (USA) (seven), Europe (five), Japan (four), Asia (four) and other regions of America (three). Specifically, 25 respondents are of the national capital, corresponding to 52.08% of the total with a 95% confidence range given by [38.79%; 65.38%], and 23, 47.92%, of foreign origin (eight with foreign capital, with a range given by [6.75%; 26.59%]; and 15 multinational subsidiaries, 31.25% of the total and the range given by [18.91%; 43.59%]). It is important to note that the fact that practically half of the companies in the sample have foreign origin allows comparing if the source of the capital matters and, therefore, to verify if they follow the local regulatory framework or the country of origin.

As for the destination market, most companies (43) declared that they were national, which means 89.58% of the total sample, whose confidence range is [81.45%; 97.71%] and only 15 abroad, therefore, 10.42%, with the range given by [2.29%; 18.55%]. The hypothesis that the proportion of companies serving each destination is the same is rejected. Regarding the size, according to the annual gross operating revenue and the original 2010 classification of the National Development Bank (BNDES), large and medium-sized companies had distinguished. Specifically, they were: 23 large (47.92%, with a range of [34.62%; 61.21%]); 15 averages (31.25%, [18.91%; 43.59%]); seven small (14.58%, [5.19%; 23.98%]) and three micro-enterprises (6.25% of the total, [0.73% 12.69%]).

It is important to highlight that 33 companies in the sample declared that they had undertaken some type of innovation that generated environmental improvements (or reduction of environmental impacts) in the last three years, that is, most companies reported having undertaken Eco-innovations. This corresponds to 68.75% of the total respondents, with a standard error of 6.30% and the 95% confidence range given by [56.41%; 81.09%]. Those that did not perform correspond to 31.25%, with a confidence range given by [18.91%; 43.59%]. It is rejected the hypothesis that the number of companies that undertake Eco-innovation is the same as those that do not, also showing the relevance of the sample. The sample companies operate in more than one segment, with emphasis on electronic components, considered the most innovative.

CHART 2
Description of the sample companies

Size		**Source of capital**		**Destination market**		**Eco-innovation**	
Micro	3	Nacional	25	Nacional	43	Yes	33
Small	7	Foreign	8	Internacional	5	No	15
Medium	15	Multinacional branch	15				
Large	23						

Source: Own elaboration based on the questionnaires.

Next, the results of the hypothesis tests will be discussed.

H1: Environmental regulation is the main driver of Eco-innovation: not corroborated

Of all the companies that declared to have carried out Eco-innovation, understood as some type of innovation (new or improved product, process, organization, management system, plant), which generated environmental improvements (as defined by Kemp and Pearson, 2008) in the last three years, the most pointed factor was the market, followed by environmental regulation (Table 1). Thus, Hypothesis 1 was not corroborated.

TABLE 1
Reasons that led companies to develop Eco-innovations

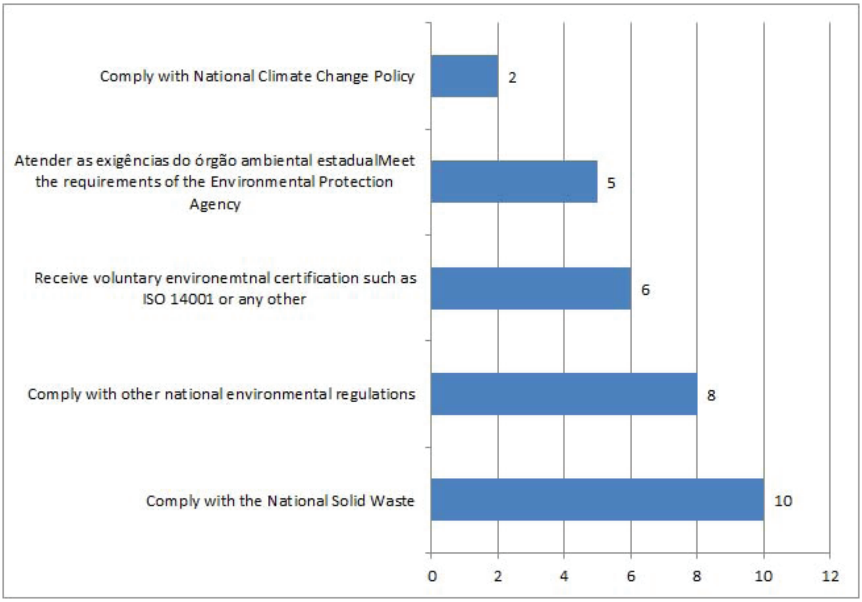
Reasons	**Answers**
Market	28
Regulation	15
Source of capital	10
Government incentive	3

Source: Own elaboration based on the questionnaires.

Given the reasons that led companies to develop Eco-innovations, 28 pointed the market (58.33%, [45.21%; 71.46%]); 25, regulation (31.25%, [18.91%; 43.59%]); ten, the source of capital (20.83%, [10.02%, 31.64%]) and three, government incentive (6.25%, [0.73%; 12.69%]). The hypothesis that the percentage of companies whose motive is the market is the same as any other motive.

Despite the importance of the market, it was possible to identify the type of environmental regulation most pointed out by companies, as shown in Graph 1. Among these, the National Solid Waste Policy (PNRS) was distinguished.

GRAPH 1
Description of the environmental regulations that motivated Eco-innovations



Source: Own elaboration based on the questionnaires.

PNRS was founded by Law 12.305/2010 and establish the prevention and reduction of waste generation, with the proposal of practicing sustainable consumption habits and a set of instruments to promote the increase of recycling and reuse of solid waste (everything that has economic value and can be recycled or reused) and the environmentally appropriate disposal of waste material (what cannot be recycled or reused) (BRASIL, 2010).

PNRS establish the shared responsibility of waste generators: manufacturers, importers, distributors, traders, citizens, and holders of urban solid waste management services in Reverse Logistics, by means of returning the products after used by the consumer. By forcing producers and traders of batteries, fluorescent lamps, and electronic products and their components to perform reverse logistics, the PNRS is expected to have a potential impact on the electronic complex (BRASIL, 2010).

According to Horbach, Rammer, and Rennings (2012), based on evidence from developed countries, existing and announced environmental regulation alone can boost Eco-innovations. However, it can be seen that, in Brazil, the mere existence of the PNRS has not been able to exert the desired effect on the sector.

According to Teodósio, Dias, and Santos (2016), the PNRS is in procrastination. Although it is considered one of the most modern environmental legislation in the world and is the result of demands and debates between civil society, legislators, and business groups, its objectives have not been achieved and its effective implementation has been postponed more than once, with deadlines and new goals redefined for 2018 and, again, 2021. From the point of view of the companies, they are responsible for the destination and reuse of the waste derived from their products, which requires more than specific actions by the companies to comply with the legislation. Changes are required from design, production, distribution, collection, among others, aiming at the product's life cycle.

In a complementary way, Mariello, Britto, and Valle (2018) highlighted the lack of institutional capacity in the implementation of goals and guidelines, that is, the lack of institutional governance of the actors involved.

Furthermore, according to institutionalist authors, such as North (1990), institutions are humanly constructed constraints that structure economic policy and social interactions. They consist of informal restrictions (sanctions, taboos, customs, traditions, and codes of conduct) and formal rules (laws, constitutions, statutes, structures of property rights, individual contracts) and their characteristics of enforcing them (by agents themselves, or by external organizations), known as enforcement. In this sense, since environmental regulation is a formal rule, its effective implementation requires enforcement. As stated by Teodósio, Dias, and Santos (2016) and Mariello, Britto, and Valle (2018), the procrastination of the PNRS and the lack of institutional training of the actors to effectively fulfill the goals of this legislation by all involved can indicate the lack of enforcement in the country.

Also, the PNRS, although well prepared and integrating producers/importers of the electronic complex, among others, is still far from other international laws that deal exclusively with the production and disposal of electronic waste. As an example, we have the Directives established by the EU in 2003: Directive 2011/965/

EU *Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment* (RoHS), which restricts the use of dangerous substances, such as mercury and lead, in electronics products; and the Directive 2012/19/EU *Waste Electrical and Electronic Equipment* (WEEE), which regulates the disposal and treatment of electronic waste. Since then, besides the exporters having to adapt to European standards, other countries and regions have adopted similar and even more stringent measures, such as China, Japan, and California (MICHIDA, 2014).

The procrastination of the PNRS, associated with stricter legislation internationally, tends to accentuate the ineffectiveness of local policy in directing the technological efforts of companies since the branches of multinationals can follow the regulatory framework of the country of origin and not of the host country.

Thus, although it is the result of a case study, the lack of confirmation of Hypothesis 1 may raise the need for other qualitative variables to be incorporated into the models of analysis of Eco-innovations' determining factors in developing countries, as well as the existence of environmental regulation, such as the effective validity and the rigor (or *enforcement* capacity) of the environmental regulation.

H2: environmental regulation has a strong influence on process Eco-innovation, while the market has a strong influence on product Eco-innovation: corroborated

According to Table 2, among the main determinants of product Eco-innovation, the market was the only significant one. Thus, concerning the influence of the market in product Eco-innovation, it can be seen that Hypothesis 2 was corroborated.

TABLE 2
Determining factors - dependent variable: Product Eco-innovation

	Coefficient	Standard Error	z	p-value	
Constant	–2,96086	1,02729	–2,882	0,0039	***
Market	3,23313	1,19270	2,711	0,0067	***
Source of Capital	–0,0388565	0,841922	–0,04615	0,9632	
Regulation	0,289988	0,774950	0,3742	0,7083	
Incentive	0,327435	1,34057	0,2442	0,8070	

Source: Own elaboration based on the questionnaires.

According to Table 3, process Eco-innovations would be insignificant in the absence of the factors "regulation" and "market" and the regulation's rate of influence is higher than the market, according to the difference between the coefficients and level of statistical significance.

TABLE 3
Determining factors - dependent variable: Process Eco-innovation

	Coefficient	Standard Error	z	p-value	
Constant	–2,38769	0,775198	–3,080	0,0021	***
Market	1,97926	0,979160	2,021	0,0432	**
Source of Capital	0,242175	0,965671	0,2508	0,8020	
Regulation	1,98969	0,842547	2,362	0,0182	**
Incentive	–1,06336	1,48666	–0,7153	0,4744	

Source: Own elaboration based on the questionnaires.

Such results are supported by two explanations. First, according to Horbach, Rammer, and Rennings (2012), it is possible to associate determining factors of Eco-innovation with different areas of environmental impact. According to the authors, customer requirements are important sources of Eco-innovations, especially related to product innovations, which reduce energy consumption and the generation of waste and the use of hazardous substances. In turn, regulations are more important in reducing atmospheric emissions (carbon dioxide, CO2 and sulfur dioxide, SO2) and liquid effluents. Thus, it can be inferred that the influence of the determining factors on Eco-innovations also depends on the type of environmental impact: the market is relevant on Eco-innovations that reduce the consumption of energy and waste, as they are linked to the consumption of the product, and regulation on process Eco-innovations, which emphasize emissions during the production process.

Second, there are implications that product changes can have during the production process. For example, the removal of lead from electronic equipment (through the use of lead-free solder) involves not only a replacement of inputs but requires the use of new machinery and production routine, thus affecting also the production process (MORO, 2014).

H3: innovative firms are also Eco-innovators: corroborated

Of the 48 companies that responded to the questionnaires, 43 (89.5%) said they had undertaken some type of innovation (new or improved product or process) in recent years. Of these 43, as shown in Table 4, 33 companies (77%) also declared to have developed Eco-innovations in the period. Thus, based on descriptive statistics, Hypothesis 3 was corroborated.

TABLE 4
Companies that declared to have innovated and undertook Eco-innovation

	Undertook Eco-innovation	Did not undertook Eco-innovation
Has performed innovation	33	10
Did not perform innovation	0	5

Source: Own elaboration based on the questionnaires.

H4: the size of the company and the source of capital matter for the development of the Eco-innovation: partially corroborated

According to Tables 5 and 6, medium-sized companies are less likely to invest 0% to 2.5% of total R&D expenditure on Eco-innovations than large companies, but a greater chance of investing 2.5% to 5% than the large ones[5].

TABLE 5
Scale of companies and share of R&D expenditure on Eco-innovations / Total R&D expenditure - dependent variable: necessary R&D expenditure to undertake Eco-innovation

Size	Coeficient	Standard Error	z	p-value	
R&D from 2,5% to 5%(1)					
Const	–0,916291	0,591608	–1,549	0,1214	
Micro	–17,9292	8744,40	–0,002050	0,9984	
Small	0,223144	1,36015	0,1641	0,8697	
Medium	2,30259	1,26491	1,820	0,0687	*
R&D more than 5%(2)					
Const	–0,510826	0,516398	–0,9892	0,3226	
Micro	–18,4524	9274,84	–0,001990	0,9984	
Small	–17,6558	6227,46	–0,002835	0,9977	
Medium	1,20397	1,32916	0,9058	0,3650	

Source: Own elaboration based on the questionnaires.
(1) Because of the linear independence of the data, expenditure on R&D up to 2.5% has been omitted and the coefficients of expenditure on R&D are presented concerning the omitted variable.
(2) The small number of small and medium-sized companies means that each combination of data (R&D and Size) has few representatives, so the expenditure of 5% to 10% and more than 10% have been grouped.

5 Despite the small number of responding companies of micro and small size, it does not interfere in the representativeness and significance of the hypothesis, since the companies associated with ABINEE are, in their majority, of larger size, because they are capital intensive. Also, according to ABINEE, about 20% of the associated companies are smaller, which corresponds to the proportion obtained (ten micro and small companies).

As Table 5 requires an omission of one of the variables (in this case, 0 to 2.5% of R&D expenditure Eco-innovation/Total R&D expenditure), it was produced a binomial regression specifically for this variable to explain its behavior, as highlights Table 6.

TABLE 6
Size of companies and share of R&D expenditures on Eco-innovations /Total R&D expenditure – dependent variable: less than 2.5% of total expenditure with R&D

Size	Coeficient	Standard Error	z	p-value	
Const	−0,262364	0,420622	−0,6238	0,5328	
Micro	−0,430783	1,29496	−0,3327	0,7394	
Small	−0,653926	0,936442	−0,6983	0,4850	
Medium	−2,37669	1,11730	−2,127	0,0334	**

Source: Own elaboration based on the questionnaires.

Although the result was significant for these ranges of investment in R&D for medium-sized companies, it is also possible to observe that large firms are more likely to invest over 5% of total R&D expenditure on Eco-innovations. Such results are represented by the estimated probabilities of the model and are shown in Table 7.

TABLE 7
Size of the companies and share of R&D expenditures on Eco-innovation /Total R&D expenditure – estimated probability method

Size	R&D expenditure/Turnover for Eco-innovations		
	Less than 2,5%	Between 2,5% and 5%	>5%
Micro	1,0	0,0	0,0
Small	0,67	0,33	0,0
Medium	0,15	0,57	0,28
Large	0,50	0,20	0,30

Source: Own elaboration based on the questionnaires.

Regarding the control of companies' capital, as shown in Table 8, the econometric test related the share of R&D expenditure in Eco-innovations (dependent variable) with the source of the companies' capital. As only the constants were significant, it is not possible to say that the source of capital influences the investment in R&D. There were no statistically significant results, so there is no significant difference between investments in R&D for national and foreign companies.

Table 8
Source of Capital and share of the R&D expenditure on Eco-innovation

	Coeficient	Standard Error	z	p-value	
R&D 2,5% to 5%(1)					
Const	−1,38629	0,790569	−1,754	0,0795	*
National Capital(2)	1,38629	0,954314	1,453	0,1463	
R&D 5% to 10%					
Const	−0,693147	0,612372	−1,132	0,2577	
National Capital	−18,6174	5897,85	−0,003157	0,9975	
R&D more than 10%					
Const	−2,07944	1,06066	−1,961	0,0499	**
National Capital	1,23214	1,26538	0,9737	0,3302	

Source: Own elaboration based on the questionnaires.
(1) Because of the linear independence of the data, expenditure on R&D up to 2.5% has been omitted and the coefficients of expenditure on R&D are presented concerning the omitted variable.
(2) Because of the linear independence of the data, companies with foreign capital have been omitted and the coefficients of R&D expenditure are presented concerning the omitted variable.

A possible explanation for the non-corroboration of this part of Hypothesis 4 may be associated with the connection between the environmental management strategy of the subsidiary with the headquarter. According to Hansem (1999), headquarters are located in countries with stricter environmental regulations and subsidiaries, in developing countries with looser regulations. If there is centralization with the headquarters' practices, management is linked to the regulatory framework of the country of origin and may bring the transfer of advanced environmental technologies; if the management mode is adapted to the local framework, there is no such effect. In other words, the results in the case of the relationship between the source of the capital and Eco-innovation do not point to the centralization of the branches with the head office.

Although not described in the hypothesis, the internationalization of companies can also be understood as access to the foreign market and it is a variable that deserves to be investigated in the determination of Eco-innovations. For most companies in the sample, the national market was identified as the main destination. However, among those who declared having the foreign market as their main destination, 80% undertook Eco-innovation, as shown in Table 9. Despite this indication, as there are few companies whose main market is foreign, it is believed that there is insufficient evidence to confirm the relationship between the variables.

Therefore, the results of this study, although for a small but relevant sample and with estimates of the models corresponding at 1%, indicate that the market, and not regulation, is the main inducing factor for Eco-innovations. Concerning types, Eco-innovations of products were determined by the market, since it is related to consumer preferences and the search for new markets, and those of process, by environmental regulation. Innovative activities, especially R&D expenditure, as well as the size of companies matter for the realization of Eco-innovations.

TABLE 9
Destination market and Eco-innovations

Main market	Eco-innovation	Did not undertook Eco-innovation	Eco-innovation (%)
National	29	14	67,0
Foreigner	4	1	80,0

Source: Own elaboration based on the questionnaires.

5. Final Considerations

This article aimed to investigate the determinants of Eco-innovations in the Brazilian electronic complex companies linked to ABINEE, through field research in the search for primary data. The sector's relevance lies in its economic, technological (for being one of the sectors with the highest innovation rates in Brazil), and environmental importance. Despite being a great waste generator after the final consumption of electronic products from the perspective of the product's life cycle, it has been treated as a clean sector by the pollutant emission criteria throughout the production process.

Based on the literature review, four hypotheses were tested, using descriptive statistics and estimates from the Logit models (binomial or multinomial): H1: environmental regulation is the main factor that induces Eco-innovation; H2: environmental regulation has a strong influence on process Eco-innovation, while the market has a strong influence on product Eco-innovation; H3: innovative firms are also Eco-innovators; H4: the size of the company and the source of the capital matter for the development of the Eco-innovation.

The sample resulting from the field research was 48 companies, of 411 associated with ABINEE, representing 12% of this population. Although it is still relevant, the sample size, limited by issues of time and costs, is not representative for the results to be extrapolated to the population or the sector as a whole. However, as the estimates were significant at 1%, the work allowed to prove or reject some hypotheses.

Even recognizing such restrictions, the non-corroboration of Hypothesis 1 can explain that other qualitative variables deserve to be incorporated into the model, especially in developing countries: the effective duration of environmental regulation, its institutional capacity building (rigor and/or enforcement), and the relationship between determining factor of Eco-innovation and environmental impact area.

Hypotheses 2 and 3 were corroborated by the model, demonstrating that there may be a strong relationship between the factor and the type of Eco-innovation and between the innovative capacity of companies in the sector and the development of Eco-innovations. Concerning Hypothesis 4, the size of the company was particularly important in R&D expenditures aimed at Eco-innovation, but the source of capital was not, pointing out that there may not be a link between the headquarters and branches in environmental management.

The work has other limitations, besides the sample size, such as estimating the environmental impacts resulting from Eco-innovations (effects on the quality of commodities and services, changes in the consumption of materials and energy), which would allow establishing a more precise relationship between types of environmental impacts and determinant factors. The interaction between companies and agents along the production chain also matters and has not been considered here. Another important element for future studies, as pointed out by Koeller *et al.* (2020), is to investigate the impact of the severity of environmental regulations and Eco-innovations undertook by other agents, such as government, suppliers, and consumers (in line with the fourth edition of the Oslo Manual), as well as expanding the scope of Eco-innovation to social activities (Social Eco-innovations). Something fundamental, not yet accomplished in Brazil, refers to the measurement of Eco-innovations.

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