Determinants of Environmental Innovation in Brazilian Manufacturing Industries

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Resumo: Os impactos econômicos da degradação ambiental tornaram-se foco de maior atenção nas últimas décadas. O agravamento dos problemas ambientais associados às mudanças climáticas e a possibilidade de esgotamento de recursos naturais básicos fez, tanto países desenvolvidos quanto em desenvolvimento, procurarem (voluntariamente ou não) novas formas de produzir e consumir. Neste cenário, a substituição ou adaptação de padrões tecnológicos atuais, visando inovações ambientais (EI), tornou-se uma alternativa para promover o crescimento sustentável. Este artigo tem como objetivo contribuir para a análise dos determinantes da inovação ambiental na indústria brasileira. Utilizando dados de painel entre 1998 e 2008, os resultados obtidos corroboram a evidência internacional sobre os determinantes da adoção de inovações ambientais. A hipótese de viés ambiental é verificada, o que indica que a regulação ambiental apresenta um papel importante para influenciar as firmas brasileiras a adotar tanto inovações ambientais tecnológicas quanto inovações ambientais organizacionais. Em relação especificamente ao processo inovativo em países em desenvolvimento, nossos resultados confirmam que empresas de capital estrangeiro têm maior probabilidade de adotar inovações "verdes", geralmente através de transferência tecnológica e acordos de licenciamento. O tamanho da firma, o fator da empresa ser exportadora e a intensidade de capital físico também são importantes determinantes da inovação ambiental nas indústrias de transformação brasileiras.

Abstract: The economic impacts of environmental degradation have become the focus of greater attention in recent decades. The aggravation of environmental problems associated with climate change and the possibility of depletion of basic natural resources has made both developed and developing countries seek (voluntarily or not) new ways to produce and consume. In this scenario, the substitution or adaptation of current technological standards, towards environmental innovations (EI), becomes an alternative to promote sustainable growth. This paper aims to contribute to the analysis of the determinants of environmental innovation adoption in Brazilian manufacturing industries. Based on panel data between 1998 and 2008, the results obtained corroborate international evidence on the determinants of environmental innovation in the international literature. The environmental inducement hypothesis is verified, indicating that environmental regulation has an important role to influence the Brazilian firms in order to adopt both technical and organizational environmental innovations. Specifically related to developing countries innovative processes, our results confirm that foreign owned firms are significantly more likely to adopt "green" innovation, usually through capital embodied technology transfer and licensing agreements. The size of the firm, being an exporting firm and physical capital intensity are also important determinants of environmental innovation in Brazilian manufacturing firms.

Keyword(s): environmental innovation, environmental inducement hypothesis, environmental regulation, econometrics.

Palavras chave: inovação ambiental, hipótese de viés ambiental, legislação ambiental, econometria.

JEL Classifications: L50, Q50, O30, O44

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1 Introduction

The economic impacts of environmental degradation have become the focus of greater attention in recent decades. The aggravation of environmental problems associated with climate change and the possibility of depletion of basic natural resources has made both developed and developing countries seek (voluntarily or not) new ways to produce and consume. In this scenario, the substitution or adaptation of current technological standards, towards environmental innovations, becomes an alternative to promote sustainable growth and contribute to improve the quality of life of future generations[1].

We define environmental innovation according to the definition proposed by the Organization for Economic Co-operation and Development (OECD) in 2009. This definition emphasizes that environmental innovations not necessarily have to be developed intentionally to preserve the environment. Rather, it includes all innovations that produce some kind of environmental gain. In this paper, we will consider: a) technical (product and process) environmental innovations[2] - including the EI that reduces resources consumption and the EI that reduces environmental negative externalities; and, b) organizational environmental innovations[3].

The economic literature on innovation has extensively discussed the determinants of general (or non-environmental) innovations usually based on one of the three broad modeling approaches: Schumpeterian, induced innovation and evolutionary approach. When studying the determinants of environmental innovations, we must also consider the relationship between innovation and the characteristics of environmental regulation.

This paper aims to contribute to this topic by investigating the determinants of technical environmental innovations and organizational environmental innovations adopted by Brazilian manufacturing firms. We use a panel data approach based on PINTEC[4] and PIA[5] data between 1998 and 2008. While the few existing studies on environmental innovation in Brazilian firms are based on cross section data, we use panel data, considering the existence of unobserved specific effects that may influence the firms' decision to adopt EI. This paper is organized in five sections (in addition to this one): section 2 presents a brief literature review of empirical studies on the determinants of environmental innovation, section 3 discusses the methodological approach used (Schumpeterian and induced innovation approaches), section 4 explains the data sources and data description, section 5 presents the econometric results and section 6 contains our final considerations.

2 Literature Review

[1] There is a branch of the literature that studies possible rebound effects arising from environmental innovation adoption, for instance when the new "green" technology reduces the consumption of energy. Briefly explaining, as energy becomes more productive, its effective price decreases and the aggregate use of energy may increase. This increased consumption of energy can potentially offset any reduction in emissions resulting from the technique effect. For more details see Turner and Hanley (2011), Sorrell and Dimitropoulos (2008) or Greening *et al* (2000), among others.

[2] According to the Oslo Manual (OECD and Eurostat, 2005), environmental innovations (or eco-innovations) can be classified in: a) technical environmental innovations; and, b) organizational environmental innovations. Technical environmental innovations can be distinguished between process and product (or services) EIs. Specifically related to process environmental innovation, we have clean technologies and end-of-pipe technologies. End-of-pipe technologies reduce the emission of pollutants by adding supplementary measures to production processes, while clean technologies reduce the use of resources and/or reduce pollution generation through the use of cleaner inputs and cleaner production methods. We can understand end-of pipe technologies as additive solutions and clean technologies as integrated and precautionary solutions. In turn, product EIs are products or services that give rise to low levels of environmental impact through its use and disposal, such as eco-houses, eco-buildings, phosphate-free detergents, water-based paints, environmental consulting, testing and engineering, etc.

[3] Organizational EI refers to new management practices focusing on environmental issues (e.g. environmental management systems).

[4] Technological Innovation Survey, conducted by IBGE (Brazilian Institute of Geography and Statistics).

[5] Annual Industrial Companies Survey, also conducted by IBGE.

There is a vast empirical literature on the firm-level determinants of environmental innovation adoption. In order to organize a brief literature review on this topic, it is interesting to distinguish these empirical studies according to the following criteria: a) how they measure the adoption (or not) of environmental innovations; b) how they measure the stringency of environmental legislation; c) how they measure voluntary motivations to adopt environmental innovation, usually related to organizational environmental innovations (with or without formal certification); d) if they analyze the relation between organizational environmental and technical environmental innovations adoption; and, e) specifically related to process environmental innovations, if they are able to distinguish between end-of-pipe and clean technologies. As mentioned in Section 1, clean technologies are seen as superior when compared to end-of-pipe technologies, both in terms of reducing environmental impacts and also in economic terms.

Environmental innovation (EI) – either process, or product or organizational EI - is usually represented by a dummy variable (that equals to one when the firm has adopted EI or zero otherwise) or by the number of “green” patents granted by the firm. EI can be also measured by the R&D investment directed to environmental innovations.

Related to the stringency of environmental policy, we can point out two common proxies used in the literature: a) pollution abatement costs – related directly to environmental compliance, since pollution abatement cost are expected to increase when regulations are tightened; and, b) number of visits of government monitoring activities. Other alternatives can be: c) number and amount of environmental assessments (notifications) received by the firm; and, d) surveys on the environmental policy design, where respondents are asked about the stringency, flexibility and stability of environmental legislation, and also about the importance of economic instruments versus command and control policies[6] (e.g World Economic Forum’s Executive Opinion Survey).

We can distinguish two ways of considering voluntary motivation. The first manner consists in including different measures of voluntary motivations as explanatory variables to explain the adoption of technical – process or product - environmental innovations. In this case, a possible way to measure voluntary motivations is through the use of surveys on the general motivations to adopt EI, such as image improvement, cost saving, reduction of environmental incidents, social pressures, customer demand, voluntary or negotiated agreements between the firm and the government, where respondents are asked directly if they adopted EI voluntarily or not. It is important to notice that this kind of survey is not very common.

The second manner is to analyze the relevant incentives for a firm to adopt environmental organizational innovations, which usually consist in voluntary measures to reduce environmental damage due to the firm activities. In this case, the most common measures of organizational environmental innovation are the ISO 14001 certification[7] and the European Union Environmental Management and Auditing Scheme (EMAS), both related to international Environmental Management Systems (EMS) norms. The literature also considers managerial activities not related to EMS standards.

EMS are organizational changes towards environmental self-regulation that include environmental reports, monitoring of environmental performance based in “*management practices that integrate the environment into production decisions, identifying opportunities for pollution and waste reductions, and implementing plans to make continuous improvements in production methods and environmental performance*”. (KHANNA and ATON, 2002). The ISO 14001 certification, in turn, is one of the most diffused forms of EMS and constitutes a voluntary organizational framework that details the procedures

[6] A relevant factor for environmental innovation adoption refers to the characteristics of environmental policy. Environmental policy measures can be classified in two main groups: a) command and control; and b) economic instruments. Command and control refer to the imposition of measures that alter the behavior of pollutants by means of specific legislation, usually imposing technological or strict emission standards. On the other hand, economic instruments allow greater flexibility in terms of adequacy technology, time and production processes, in order to reduce the environmental impact.

[7] Sponsored by the International Organization for Standardization (ISO).

to manage the impacts of the firm activities on the environment and has an attempt to get ahead from the existing government regulations. The ISO 14001 certification requires third party certification and investigation.

Finally, there is another branch of the literature that investigates if the adoption of EMS or other environmental management techniques improves the firms technical environmental performance. We are not going to explore this approach in this paper. For more details see Khanna *et al* (2009), Ziegler and Nogareda (2009), Wagner (2009), Rennings *et al* (2006) and Anton *et al* (2004), among others.

Based on the concepts aforementioned, we present below a brief literature review on the firm-level determinants of EI. Frondel *et al* (2007) use a multinomial logit model applying a categorical variable to reflect three distinct unordered choices of EI: a) end-of-pipe technologies, b) clean technologies; and c) no implementation of EI. They use dummy variables to measure both the environmental regulation stringency and the impact of regulatory measures. The "policy stringency" variable equals to one if the respondent considers the environmental police stringent and equals to zero if he considers the policy moderately or not stringent. The "regulatory measures" variable equals to one if the firm declares that input bans, technology or performance standards were very important motives to adopt EI.

Based on 2003 data for seven OECD countries (Canada, France, Germany, Hungary, Japan, Norway and the US - totaling 4,186 observations), the authors indicate a positive and significant correlation between stringent environmental regulation and end-of-pipe technologies, while the correlation between stringent policy and clean technologies was not significant. They argue that this particular result can be explained by the fact that command and control was still the dominant environmental policy at that time, which usually "*impose technology standards that can only be met through end-of-pipe abatement measures*". The study also attempted to analyze voluntary motivations to adopt the aforementioned EIs. However the "voluntary or negotiated agreements" dummy variable was not significant in any of the cases. On the other hand, the "prevention of environmental incidents" (dummy variable) was significant and positively related with both end-of-pipe and clean technologies. Clean technologies, in turn, were favored by cost saving motivations (dummy variable) tending to be market-driven instead of regulation-driven.

Brunnermeier and Cohen (2003) studied the determinants of environmental innovation in the US manufacturing industries between 1983 and 1992. The authors used the number of successful environmental patent applications granted to the industry as a proxy to environmental innovation. They were interested in understanding how the adoption of EI by the US industries responded to changes in pollution abatement expenditure (US$ million) and to changes in the number of air and water pollution related inspections, proxies to environmental policy stringency. They estimated four different models (fixed effects, poisson, negative binomial fixed effects and negative binomial random effects) and obtained robust results across them, concluding that there is a positive and significant relation between pollution abatement expenditures and the number of "green" patents granted by the firm. The coefficients on the number of inspections are insignificant and the explanation proposed by the authors is that this occurs because the number of inspections might be highly correlated to the pollution abatement variable. They also reported positive and highly significant coefficient in the value of industry shipments control variable (US$ million), indicating a positive relation between industry output and patenting activity.

Horbach *et al* (2012) tested whether different types of environmental innovation are driven by different determinants. Based on the German 2009 Community Innovation Survey (CIS) covering 7,061 firms in mining and quarrying, manufacturing, energy and water supply and service sectors, the authors defined twelve different types of EI according to the environmental impact caused by the EI. The first nine types are related to process EI: 1) reduction on the consumption of materials; 2) reduction on the consumption of energy; 3) reduction on the emission of CO_2; 4) reduction on the emission of other air pollutants; 5) reduction on water pollution; 6) reduction on soil pollution; 7) reduction on noise pollution; 8) replacement of hazardous substances; 9) recycling of waste, water or materials. The other three types are product EIs related to the after sale use of the product. All the different EIs were measured by dummy variables and the authors estimated a probit model. According to the results obtained, except for the EIs that impact on the reduction of material and energy consumption, present and future environmental regulation registered positive and significant correlation with the adoption of the other ten different types of EI. "Present regulations" and "future regulations" variables were measured as dummy variables related respectively to: a) the relevance of the fulfillment of laws and regulations; and, b) the anticipation of future regulations. The adoption of EMS (dummy variable) presented positive and significant correlation with all the different types of EI considered. Related to voluntary motivations, cost savings turned out to be an important determinant in the adoption of energy and material saving EI; also, the customer requirements coefficient was significant and positively correlated to product EI. Cost savings were measured by a dummy variable that equals to one when the cost reduction was highly relevant to innovate. Customer requirements were also represented by a dummy variable that equals to one, according to the firm's perception of customer demand for EI.

Demirel and Kesidou (2011) used a dataset on 289 UK firms that responded the DEFRA[8] Government Survey of Environmental Protection Expenditure in 2005 and 2006. The study considers three different types of environmental innovation (all of them measured as dummy variables): a) end-of-pipe technologies, b) integrated cleaner production technologies, and, c) environmental R&D – defined as the "*use of R&D to generate new or improved products and processes with environmental benefits*". The authors estimated a Tobit model and investigated the impact of environmental regulation (command and control policy), environmental taxes (economic instrument), ISO 14001 certification and efficiency improvement on the firms' probability to innovate in order to preserve the environment. Both environmental regulation and environmental taxes variables are binary variables that assume the value one if each of them has been effective to the firms' decision to innovate. Efficiency improvement was measured as equipment upgrades (dummy variable that equals to one if the firm invested in environmental protection because of equipment upgrade) or cost savings (equals to total costs savings resulting from environmental improvements, measured in pounds sterling). The results of the study confirm that different types of EI have different determinants. End-of-pipe technologies are stimulated by environmental regulations (usually characterized by command and control measures), equipment upgrade motives and ISO 14001 certification. Clean technologies are mainly driven by efficiency improvement motive (equipment upgrade) and Environmental R&D is positively correlated with environmental regulations, cost saving motives and ISO 14001 certification. The study indicates that ISO 14001 certification is important to stimulate firms to invest in Environmental R&D. Environmental taxes, in turn, was not significant to any of the three types of EI considered. According to the authors, in the UK "*environmental taxes have not been frequently used as means of regulating pollution levels since environmental laws have historically been the preferred policy tool in this field*".

Using OLS fixed and random effects models, the panel study conducted by Del Rio *et al* (2011) with Spanish manufacturing industries in the period 2000-2006, confirmed the relevance of the stringency of environmental regulation and physical capital intensity to explain the investment in environmental technologies. The authors also stated that the determinants of EI are likely to differ between end-of-pipe and clean technologies adoption. In the study, EI is measured as the investment in environmental technologies to value added ratio and environmental regulation stringency is represented by the intensity of environmental protection expenditures to value added ratio. Physical capital intensity equals the investments in material assets to turnover ratio. Furthermore, export intensity (exports to turnover ratio) was negatively correlated with EI, indicating, according to the authors, that "*environmental protection is often done in sectors that are (or have been in the past) protected and highly regulated, such as energy.*"

Concerning the determinants of organizational environmental innovations adoption, Frondel *et al* (2008) estimated a probit model based on an OECD survey performed in 2003 with 899 firms in Germany. Their results indicate that EMS adoption (dummy variable) was positively correlated with the enhancement of corporate image (dummy variable), firms' size (number of employees) and internal forces such as corporate headquarters employees and shareholders pressure (dummy variable). It was also negatively

[8] Department for Environment, Food and Rural Affairs (DEFRA).

correlated with cost savings motivations (dummy variable) "*probably because survey respondents expect EMS adoption to be costly*".

Cole *et al* (2006), using data from 400 Japanese firms in 1999 and OLS regression, identified the factors that influence the adoption of 13 different aspects of a firms' environmental management process. These aspects are related to two broad groups: a) the management and control of specific environmental problems (such as management of total CO_2, treatment of industrial waste, water pollution control, among others); and, b) the quality of the general structure and systems that firms employ to handle environmental issues (ISO 14001 certification, environmental accounting, among others). The 13 different aspects are scored and based on those scores the authors constructed an "overall environmental management performance" index which ranges between 48 and 70 (the higher the more sophisticated). The results obtained indicate that foreign direct investment (dummy variable), firms that export (dummy variable), physical capital intensity (capital stock per worker) and size of the firm (total employment) are significant and positively correlated with the overall management performance of the firm. The interpretation given by the authors is that Japanese firms that embark on FDI in more regulated countries will raise standards in Japan, or other possibility is that multinationals owned firms are subject to closer national and international monitoring when compared to domestically owned. The exports variable indicates that a firm that exports receives more influence of international competition and monitoring encouraging, to have better environmental management practices. Firms intensive in capital tend to be more pollution intensive, and hence, are expected to adopt more stringent environmental management. And, finally, the structure and resources necessary to implement environmental management are more likely to be encountered in larger firms.

Similarly, Anton *et al* (2004) constructed an overall environmental management variable that counts the different environmental management practices (among 13 options) adopted by the firm. The authors use Poisson and quantile regression methods, to assess the comprehensiveness of environmental management for S&P 500 US firms, between 1994-95. Across all the different models estimated, the results indicate a positive correlation between "potentially responsible parties (PRPs)" and the adoption of comprehensive EMS. Firms are listed as PRPs if they had already been held liable for contamination caused by their hazardous waste streams. Also firms classified as "final goods" producers (dummy variable that equals to one when the firm is primarily selling products or services to the consumers) are in closer contact to consumers and hence fell greater pressure or benefit more from improving their environmental awareness. Therefore, the "final good" variable registered a positive and significant impact on comprehensive EMS. In the same direction, toxic releases (defined as the sum of on-site toxic releases and off-site transfers) are positively correlated to EMS since firms that register larger volumes of toxic releases are more likely to face social pressures from stakeholders or communities, in order to improve their environmental management practices.

Focusing on the determinants of EI in developing countries, Albornoz *et al* (2009)[9] suggested that foreign owned firms are highly and positively correlated with EMS adoption (dummy variable equal to one if the firm has adopted EMS) in Argentinian manufacturing industries. This highlights the importance of technology and management practices transfer from developed to developing countries. This result is consistent across all specifications adopted and, particularly, the baseline regression indicates that foreign-owned firms are nearly twice as likely as domestic firms to have implemented EMS. The authors used a logistic regression model based on 1,187 Argentinian firms, between 1998-2001 (INDEC[10] data).

Specifically related to studies on Brazilian manufacturing firms, Marta *et al* (2011) analyzed the determinants of pollution abatement investment (measured as log of total investment directed to reduce or prevent environmental damage) in 2007. The study uses OLS regressions on 8,218 Brazilian firms and concludes that the main determinants of pollution abatement investment are the size of the firm (total employees) and the firms' productivity (measured as industrial transformation value to employees ratio),

[9] The authors are especially interested in verifying the presence of environmental spillovers in the sense that foreign firms have been known to directly encourage the dissemination of environmental related knowledge and technologies.
[10] Institute of Statistics and Censuses in Argentina.

both variables with positive signs. On the other hand, the coefficients that correspond to age of the firm (years of operation) and export (measured as a dummy variable) are significant and negative.

Queiroz (2011) used a probit model based on 2008 PINTEC data and analyzed the determinants of EI with high or medium impact on the reduction of environmental damage (dummy variable). The study suggests that cost saving impacts, market share expansion and adjustment to internal and/or external general market norms are positively correlated to the adoption of this particular type of EI.

Seroa da Motta (2006) used data from a research conducted by CNI (National Industry Confederation) in 1997 on "Environmental Management in Brazilian Industry", along with 325 medium and large firms. The author constructed an index of environmental practices adoption and used OLS regression to analyze its determinants. The results obtained indicate that the main determinants of environmental practices are the size of the firm (total employees), cost reduction motivation (dummy variable) and social pressures of NGOs and local communities (dummy variable).

Finally, Ferraz and Seroa da Motta (2001), based on a 1996 PAEP[11] database on 10,070 firms located in São Paulo State, concluded that size, foreign ownership, export intensity and environmental notification increase the firm's probability to realize environmental investment (dummy variable). The authors utilized probit, probit instrumental variable and Heckman Probit regression models, and the results are consistent across the different models. Environmental investment is a dummy variable equal to one if the firm realizes either investment in cleaner inputs, investment in cleaner production processes or investment in waste treatment. Foreign ownership is a dummy variable, export intensity is measured as exports to total sales ratio, and environmental notification is the number of fees or notifications received by the firm between 1993-95, issued by CETESB[12], and also the number of CETESB agencies in the city where the company is located.

3 Schumpeterian and Induced Innovation Approach

Our modeling strategy is based on the traditional Schumpeterian approach complemented with the induced innovation hypothesis. The literature on the economics of innovation was originated with Schumpeter (1942) writings, which pointed out the central role of technological progress to economic growth. In determining firms' innovative activities, Schumpeter focused on the importance of firm size and market structure. In his argument, large firms with market power (concentrated markets or monopolist firms) would have advantages in innovating. Large firms usually deal in a lesser extent with financing problems since usually generate more stable internal funds.

Furthermore, large firms have greater ability to deal with risky R&D activities, counts on economies of scale in maintaining R&D laboratories, and in some circumstances, provide economies of scope because of their diversified nature. In the modeling strategy adopted in this paper we used the number of total employees as a proxy to the firm's size. We also introduced physical capital intensity since usually those industries that are more intensive in capital generate greater volumes of pollution – and consequently face larger abatement costs - than those intensive on labor. According to Cole *et al* (2005) this fact occurs in part due to the positive relation between physical capital intensity and energy use, intensive in the combustion of fossil fuels (largely pollutants).

Market power, in turn, stimulates the firm to invest in innovative activities because it reduces rivalry and uncertainty associated with innovation process. Additionally, some form of market power (even temporary), deriving from innovations (e.g. patents) incentives firms to invent. Patents and other forms of intellectual property are possible solutions to appropriability problems. (COHEN, 2010)

Schumpeter also distinguished between three stages in the process of technological change: a) invention - the first step in developing a new technological process or product; b) innovation - when the invention is

[11] Economic Activity Survey of São Paulo (PAEP) held by SEADE (State System for Data Analysis).
[12] Company of Environmental Sanitation Technology (CETESB) of São Paulo State.

commercialized; it includes organizational innovation besides technological innovations; and, c) diffusion – corresponds to wider application of innovations.

Concerning innovation processes in developing countries - focus of analysis in this study, it is important to reinforce that in many situations it is difficult to differentiate between the effects of innovation and the diffusion stages. Conventionally, innovation and invention are assumed to be activities concentrated in developed countries, while developing countries concentrate the diffusion of new technologies embodied in capital goods purchased from more advanced economies. Indeed, technology transfer from developed to developing countries can occur through several channels such as multinational parents, international trade and licensing agreements. Multinational parents often transfer technology to their subsidiaries, although in many situations the technology transferred is mature or, in other words, is not the most updated. Concerning international trade, firms can import frontier technology embodied in capital goods or inputs and/or can export to buyers endowed with more advanced technologies and hence be in contact with new technologies. International trade also enhances international monitoring in relation to the firms' environmental practices (ALMEIDA and FERNANDES, 2008).

In this scenario, developing countries are seen simply as "borrowers" of technology from developed countries. However we understand that this interpretation of technology diffusion is misplaced. According to Bell and Pavitt (1997) the diffusion stage "*involves more than the acquisition of machinery or product designs and the assimilation of related operating know-how".* In fact, innovation usually continues in the diffusion process, through adaptation to particular uses and conditions in developing countries' firms. Besides adaptation, the new technologies can be improved in the post-adoption phase by incorporating incremental developments and modifications in accordance to continuing learning curves in industrial production. Thus technology diffusion leads to creative and complex incremental technological change.

Trying to address the importance of transferred technology by multinational parents we included the "foreign owned" variable in the model tested in this paper. We also added "export intensity" intending to measure the impact of international trade on the firms' probability to adopt environmental innovations.

More recently, in addition to Schumpeterian traditional approach, the determinants of technological change and innovation adoption have been studied according to the induced innovation hypothesis[13]. The induced innovation approach (originated from Hicks (1932) ideas) states that economic motives influence the rate and direction in which the innovations are developed[14].

According to Acemoglu[15] (2002), the direction of technical change is determined endogenously by the interaction between relative prices, market size, the elasticity of substitution between the input factors, and innovation costs (relatively to current or "state" composition of R&D). The relative prices favor innovations directed at scarce factors; the market size favors innovations directed at abundant factors. In the case of the elasticity of substitution between the input factors, whenever the elasticity of substitution is low, the relative price effect is more powerful, and technological changes will be biased towards the scarce factor. On the contrary, when the elasticity of substitution is high, market size effect is more powerful and technological innovation will be directed at abundant factors.

Focusing on environmental innovations, both scarcity of natural resources and environmental regulation (implicitly or explicitly) lead to more expensive environmental inputs, changing relative prices, and thus, they can be understood as a possible explanation to technological change directed towards "green" technologies. In this sense, Newell *et al* (1999) proposed the *environmental inducement* concept, including *inducement by regulatory standards* in the induced innovation hypothesis, suggesting an

[13] There is also the evolutionary approach, which views technological progress as an evolutionary process. In this approach firms engage in satisficing behavior, without requiring its optimization. We are not going to base our analysis on this approach. For more details on the evolutionary theory see Dosi and Nelson (2010) and Cohen (2010).

[14] For more details on biased technological change theories, see Lucchesi et al (2014b).

[15] Acemoglu's model is based in a CES production function and considers a scale effect (the growth rate of the economy increases as the population increases) and treats factor supplies as given (not considering their response to relative prices). For more details see Acemoglu (2002).

important relation between environmental policy and technology change. According to Jaffe *et al* (2003) it is very difficult to test the environmental inducement hypothesis because it is not easy to measure the extent of inducement across firms: "*more generally, non-price regulatory constraints can fit with the inducement framework if they can be modeled as changing the shadow or implicit price that firms face emitting pollutants*". Since shadow price of pollution or environmental inputs are not easily observed, we must use proxies for them. Such proxies are generally related to environmental regulations characteristics, trying to measure its stringency, expenditures on pollution abatement or prices of polluting inputs (e.g. energy, carbon fuels). In this paper we are going to use the Brazilian environmental legislation count variable as a proxy to the stringency of environmental regulation. The Brazilian environmental legislation variable considers the number of laws, decrees, resolutions, etc., per Brazilian State, in a three years interval period.

Porter and Van der Linde (1995) also stressed the role played by stringent environmental legislation on firms decision to adopt environmental innovations. The controversial Porter Hypothesis[16] (PH) suggests that well designed environmental regulation may spur innovation that, in turn, will partially, or more than fully, offset its initial compliance cost.

In order to facilitate PH analysis, we can disaggregate it into two component parts: a) the first component part refers to the relation between the stringency of environmental regulation and innovation adoption; and, b) the second part deals with the proposition that environmental innovation can more than offset its initial cost and subsequently increase the firm's business performance. In this paper we are going to deal with the first part of PH.

There are many critiques to PH, especially related to its second part. However, turning the attention to its first component part, we can mention as the main critique the difficulty to design well fitted, stringent and at the same time efficient environmental regulations. In particular, PH indicates that what it means by "*properly designed regulations*" favors the utilization of economic instruments in place of command and control policies. Unfortunately, the Brazilian environmental legislation presents few economic instruments, favoring command and control policies, so in this case, we are not going to discriminate between them. Therefore we are going to use the Brazilian environmental legislation variable as a proxy to test the stringency of environmental regulation in the PH sense.

In Brazil, the control of pollution is decentralized to states, occurring through environmental state agencies subordinated to federal legislation. Specifically related to industrial pollutant activities – the focus of this thesis - , Seroa da Motta (2006) indicates that each state is responsible for its own territorial monitoring and usually firms can "*face two different types of legal sanctions: (i) administrative fines imposed by the Environmental State agencies; and, (ii) remediation and clean-up legal sanctions imposed by the judiciary.* Also, according to the environmental criminal law[17] established in 1998, manufacturing firms which: a) launch solid, liquid, gaseous, waste, oil or oily substances, in violation of the requirements established in laws or regulations; or b) fail to adopt, when required by the competent authority, precautionary measures in case of risk of serious or irreversible environmental damage, can be penalized with imprisonment of their legal representatives between one to five years.

Given the complexity of Brazilian environmental legislation, particularly at the state level, we conducted a detailed survey[18] (until 2008) on the laws, decrees, resolutions, ordinances and regulatory instructions specifically related to the industrial activity, of special interest in this thesis. The survey was conducted according to five relevant topics: 1) industrial activities; 2) inspections, monitoring and sanctions; 3) industrial effluents and waste; 4) economic instruments; and, 5) specific industries. As a result of this

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[16] Jaffe and Palmer (1997) suggest three different interpretations to the Porter Hypothesis: 1) the narrow version (concerning more flexible regulation): "*certain types of environmental regulation stimulate innovation*", 2) the weak version: "*regulation will stimulate certain kinds of innovation*", and 3) the strong version: "*environmental regulation is a free lunch (or even a paid lunch), that is, regulation induces innovation whose benefits exceeds its costs, making the regulation socially desirable, even ignoring the environmental problems it was designed to solve*".

[17] Federal Law N° 9605.

[18] To the best of our knowledge this kind of survey is not yet existent in the Brazilian literature.

survey, we constructed a count variable that counts the number of laws, decrees, resolutions, ordinances and normative instructions at the state level concerning the five topics mentioned across the Brazilian states, in a three year basis between 1998 and 2006[19] (Table A.1).

So, the modeling strategy utilized in this paper is based in the Schumpeterian and environmental inducement approaches presented along this section. Therefore, we estimated pooled OLS, fixed effects and logit regressions according to equation (1):

$$\mathbf{EI}_{it} = \beta_1(\text{EnvReg}_{it-1}) + \beta_2(\text{Size}_{it}) + \beta_3(\text{Export}_{it}) + \beta_4(\text{Foreign}_{it}) + \beta_5(\text{Capital}_{it}) + \delta_t + \mu_{it} \qquad \mathbf{(1)}$$

where:

$i = 1, 2, \ldots, N$ – cross section firms units (CNAE[20] 3 digit);

$t = 1, 2, \ldots, T$ – time period (years);

$\mathbf{EI}_{it}$ – set of environmental innovation dummies (at least one, all, environmental impact reduction and safety improvement, biological effluent treatment and environmental management techniques);

$EnvReg_{it-1}$ – lagged Brazilian environmental regulation count variable;

$Size_{it}$ – Size of the firm - proxied by total number of employees;

$Export_{it}$ – Exporting firm - measured as a dummy variable that equals to one when the firm exports or zero otherwise;

$Foreign_{it}$ – Foreign ownership - measured as a dummy variable that equals to one when the firm is owned by foreigners (more than 51% of capital) or zero otherwise;

$Capital_{it}$ – Physical capital intensity – measured as capital stock to total employees ratio;

δ_t - time effects

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ - parameters to be estimated

μ_{it} – error term

It is important to notice that Brazilian environmental regulation is lagged in one period, since there is an interval between the law publication and the effective adoption of environmental innovations by the firm.

As a robustness test, we also tested the determinants of pollution abatement investment (in place of environmental innovation), using pooled OLS and fixed effects estimation methods. In this sense, we estimated equation (2) considering pollution abatement investment:

$$\text{PAI}_{it} = \beta_1(\text{EnvReg}_{it-1}) + \beta_2(\text{Size}_{it-1}) + \beta_3(\text{Export}_{it-1}) + \beta_4(\text{Foreign}_{it}) + \beta_5(\text{Capital}_{it-1}) + \delta_t + \mu_{it} \qquad \mathbf{(2)}$$

where,

PAI_{it} – pollution abatement investment – measured as a percentage of total investment.

In equation (2) all the explanatory variables are lagged (except foreign ownership) because, once again, there is a lag of time between the aforementioned variables and the decision to invest in pollution abatement. The foreign ownership is not lagged because the firms' capital origin does not change very frequently and thus we suppose that it is fixed along all the period considered (1997-2008).

In the pooled OLS and pooled logit regressions we also considered industry sector dummies and state dummies. In the OLS and logit fixed effects estimations it is not possible to control by industry and state characteristics because they are already included in the fixed effects.

[19] More details about the environmental legislation variable constructed can be obtained under request.
[20] National Classification of Economic Activities.

4 Data sources and description

The data used in this paper combine two different databases, both calculated by IBGE (Brazilian Institute of Geography and Statistics): a) PIA - Annual Survey of Industrial Companies, and, b) PINTEC - Technological Innovation Survey. PIA and PINTEC data are classified according to the Brazilian government's National Classification of Economic Activities – CNAE version 2.0. These microdata are confidential and the access to them is possible only at IBGE´s secrecy room with previous authorization. All monetary values were corrected by IPA_OG[21] (wholesale price index) sectoral price index and are expressed in terms of 2008 values.

It is important to notice that, while PIA survey is conducted every year, PINTEC survey is conducted every three years, following the Oslo Manual (OECD document establishing guidelines for collecting and interpreting data on industrial innovation) and Community Innovation Survey (CIS) recommendation.

Unfortunately, according to the available data in Brazil, it is not possible to distinguish process EI between end-of-pipe technologies and clean technologies. Either, it is not possible to distinguish between EI adopted to comply with command and control measures or motivated by economic instruments.

In order to construct a panel data, we used the four PINTECs conducted until now: PINTEC 2000 (refers to the period between 1998 and 2000), PINTEC 2003 (between 2001 and 2003), PINTEC 2005 (between 2003 and 2005) and PINTEC 2008 (between 2006 and 2008) and merged the PINTEC's variables (environmental innovations and capital origin variables) with PIA's variables in the first year of PINTEC three year interval period corresponding to: 2006, 2003, 2001 and 1998.

The panel database covers 20 industrial sectors in 27 states. The sectors of pulp and paper (3% of total industrial firms in 2008 according to PINTEC data), nonmetallic minerals (4%), oil and oil products (3%), metallurgy (8%), and chemicals (4%) are among the most polluting sectors considered in accordance with international literature[22] and the Brazilian Federal Law N^{o} 10.165. The southeast region concentrates 62% of total industrial firms in 2008 (according PINTEC data), followed by the south regian (23%) and northeast region (11%).

We considered as technical environmental innovation those product or process innovations that had high our medium impact in a) reducing the resources consumption; and b) reducing the environmental negative externalities, both a) and b) are defined as protecting the environment. As organizational environmental innovation we considered the adoption of environmental management techniques[23].

Based on PINTEC's data, we constructed two grouped dummy variables in each 3-year period covered by the survey. The first grouped dummy variable (named "EI at least one") was constructed in order to represent those firms that had adopted at least one of the following four different types of technical EIs: a) EI with high or medium impact in reducing raw material consumption, b) EI with high or medium impact in reducing energy consumption, c) EI with high or medium impact in reducing water consumption and d) EI with high or medium impact in reducing environmental impact and improving safety requirements[24]. The second grouped dummy variable (named "EI all") was constructed to measure those firms that have adopted all the four different EIs aforementioned. Therefore, in the constructed panel database we have three technical environmental innovations - "EI - at least one" (41% of total firms adopted at least one type of EI in PINTEC 2008), "EI – all" (10% of total firms adopted all EI in 2008) and "Environmental impact reduction and/or safety improvement" (30% of total firms in 2008) - and one organizational environmental innovation - adoption of "Environmental management techniques" (50% of total firms in 2008).

[21] Calculated by FGV - Getúlio Vargas Foundation.

[22] e.g. Albornoz et al (2009)

[23] The adoption of environmental management techniques variable was not available in PINTEC 2000.

[24] It is not possible to distinguish between environmental and safety effects before PINTEC 2005. The question regarding this impact includes both effects in PINTEC's 2000, 2003 and 2005 questionnaires. Only in PINTEC 2008 questionnaire the environmental and safety effects were separated in two different questions.

Concerning the independent variables, we used: a) firm's size variable - measured as log number of total employees; b) exporting firm variable – a dummy variable equal to one if the firm exports, zero otherwise; c) foreign ownership variable - a dummy variable equal to one in case of foreign ownership, zero otherwise; and, d) physical capital intensity variable – equals to log of capital stock to total employees ratio. We also used an environmental regulation variable, which is a variable that counts the number of environmental laws, decrees, etc, per Brazilian state, and intends to be a proxy to regulation stringency: the greater the number of laws, the greater the stringency of environmental regulation. The environmental regulation variable was measured in the preceding three year interval to each PINTEC survey (1995-1997; 1998-2000; 2000-2002 and 2003-2005 respectively). Table 1 presents the descriptive statistics[25] for the panel database (1998-2008) constructed.

Finally, a second panel database was created to analyze the determinants of pollution abatement investment effect, available in PIA 1997, 2002 and 2007 surveys. The pollution abatement investment variable is equal to the percentage of investments spent in reducing or controlling emissions of pollutants that result from production process, or to attend environmental regulations (totaling 4,6%, 6,2% and 5,8% 1997, 2003 and 2007, respectively). The measurement of this variable includes the acquisition of industrial machines that incorporate the design of clean technology, acquisition of other equipment and construction of treatment stations.

In this second panel database we considered lagged firm size, export intensity, physical capital intensity and environmental regulation. Pollution abatement investment was measured in level and foreign ownership (assuming that capital origin does not change frequently) is measured in level, on a three year basis interval, according to PINTEC's methodology. As mentioned in Section 3, all the explanatory variables are lagged (except foreign ownership), assuming that there is a lag of time between the aforementioned variables and the decision to invest in pollution abatement.

5 Empirical Results

Tables 2 to 5 present the estimation results, related to the determinants of technical and organizational environmental innovations in Brazilian manufacturing firms, between 1998-2008. Table 6 presents the results for the determinants of pollution abatement investment between 1997-2007.

Related to the determinants of EI adoption, we estimate four different models, which can be verified in Tables 2, 3, 4 and 5: a) pooled OLS (columns 1 and 2), b) linear fixed effects (columns 3 and 4), c) pooled logit (columns 5 and 6) and d) logit fixed effects (columns 7 and 8). All the regressions are weighted by sampling frequency and establishment size[26]

The advantage of using fixed effects models (linear or logit) is that they control unobservable effects, avoiding possible omitted variable bias. In particular, logit and logit fixed effects models were utilized because of the binary characteristic of the dependent variable, as the logistic function is restrained to range between 0 and 1. Besides that, the main difference between linear OLS and nonlinear logit models is that the linear model assumes that the regressors present constant marginal effects, while the logit model assumes diminishing partial effects. The marginal effects of the logit estimates (columns 5 and 6) and logit fixed effects estimates (columns 7 and 8) were calculated at the means of the independent variables, and are comparable with the OLS estimates.

In Tables 2, 3, 4 and 5, column (1) differs from column (2) - and analogously column (3) from (4) and column (5) from (6) – due to specification purposes. The first column of each model (columns 1, 3 and 5)

[25] Maximum and minimum values of the variables presented in the table were not shown because it is forbidden to calculate such statistics when using IBGE's confidential data in secrecy room.

[26] The rationale for weighting by size (standard in skill biased technological change) is to give larger firms a bigger weight, just as we would do if aggregating to macro economy. Besides that, measurement error is worse for smaller firms, so this also helps in this dimension (CAROLI and VAN REENEN, 2001). In the logit and logit fixed effects models the weights were calculated as average weights per firm.

includes only the environmental legislation count variable, while the second column of each model (columns 1, 4 and 6) includes the control variables. Additionally, dummy year variables (2003, 2005 and 2008) were included in all regressions. Besides that, 19 industry-specific dummies and 26 state dummies were included in the pooled OLS (columns 1 and 2) and logit models (columns 5 e 6). Table 2 shows the results of the estimation of the influence of each explanatory variable on the firms' probability to adopt at least one type of technical environmental innovation[27] (equation 1) - approximately 43% of the firms (mean of dependent variable). Taking Table 2 as a whole, we can observe that the estimates are consistent across the four different models. The same explanatory variables are significant in each model (with the same level of significance in most of the times) and also they have the same signal across the different models.

The environmental regulation variable is highly significant and has a positive coefficient in all models, despite its small magnitude, ranging from 0.002 to 0.009. This means that one additional environmental law increases the firm's average probability to adopt at least one type of technical EI between 0.2 p.p. (percentage point) and 0.9 p.p. This result confirms the importance of the environmental regulation in influencing firms' probability to innovate in order to reduce environmental impact, in line with Horbach (2012), Demirel and Kesidou (2011), Del Rio (2011), Brunnermeier and Cohen (2003) and Frondel *et al* (2007) findings.

As expected, the size of the firm seems to be an important issue to innovate "green". This variable is also highly significant across the models and indicates that 1% increase in the number of employees would increase the average probability to innovate between 0.011 p.p. and 0.107 p.p.. This result is consistent with Brunnermeier and Cohen (2003), Marta *et al* (2011) and Ferraz and Seroa da Motta (2001).

In the same way, foreign ownership and physical capital intensity have a positive and significant influence in the firms' probability to adopt EI. As mentioned in Section 3, in developing countries, foreign ownership is frequently highlighted as of particular importance to technology convergence to that of high-income countries, especially due to capital embodied technology transfer. Being a foreign owned firm, instead of domestically owned, increases the average probability of innovating green between 1.9 p.p. and 3.4 p.p. (columns 2 and 6 respectively). This result confirms Albarnoz *et al* (2009) and Ferraz and Seroa da Motta (2001) findings. In fact, in our analysis, foreign ownership variable registered the greater coefficient magnitude indicating the importance of technology transfer in increasing the average probability to adopt EI.

In turn, physical capital intensity coefficient is positive and highly significant, which suggests that industrial firms with greater number of machinery and equipment per employee have greater probability of introducing environmental innovation in their production processes or products. The idea behind this argument is that capital-intensive firms are usually more pollutant and hence tend to invest more in new technologies in order to reduce environmental damage. If physical capital intensity increases in 1%, the average probability of adopting green technologies will raise between 0.006 p.p. and 0.026 p.p., depending on the model analyzed. Cole *et al* (2006) and Del Rio (2011) also find positive coefficients on physical capital intensity.

On the other hand, the exporting firm variable registered mixed results, ranging from -0.7 p.p. (column 8) to 2.4 p.p. (column 6). According to the literature, we expected that competition in international markets tends to spur environmental innovations (verified in columns 2 and 6).

In order to verify the robustness of the estimates presented in Table 2, we realized the estimation of the determinants of other two technical EIs: a) "EI – all": dummy variable that equals one when the firm has adopted all the four different types of technical EI – Table 3; and, b) "Environmental impact reduction and safety improvement" - we isolated one of the four types of technical environmental innovation, the "environmental impact reduction and safety improvement", since it is directly related to environmental

[27] As mentioned in Section 2.4, we utilized four different types of technical environmental innovations, defined as technical innovations that had medium or high impact on: a) the reduction of raw material consumption; b) reduction of energy consumption; c) reduction on water consumption; and, d) reduction of environmental impact and safety improvement.

protection purposes – Table 4. As said before, the structure of Tables 3 and 4 are similar to that utilized in Table 2.

Interestingly, concerning the adoption of all types of technical EI (approximately 10% of the firms – mean of dependent variable), in Table 2, we observe that the magnitudes of the coefficients on Environmental regulation are approximately the same when compared to Table 2 results (adoption of at least one type of EI), ranging from 0,002 to 0,008. One possible interpretation to this fact is that the influence of regulation enforcement is related to meet the requirements of environmental protection, independent of the number of different types of EI adopted.

The firms' size variable registers mixed results. On pooled OLS regression (column 2) and Logit regression (column 6) the coefficient on Firm Size was positive, while on OLS fixed effects (column 4) and logit fixed effects (column 8) it was negative. Once again, exporting firms registered mixed results, being significant and positively correlated to the adoption of all EIs (columns 4, 6 and 8) and negatively correlated to the adoption of all EIs in column 2. In opposition, the partial effects of being a foreign owned firm (4.4 p.p. - column 2 and 1.1 p.p. - column 6) and of physical capital intensity (ranging form 0.010 p.p. - column 2 to 0.044 p.p. - column 8) are highly significant and positively correlated to the adoption of all EIs.

Table 4 presents the estimations results on the determinants of the adoption of a specific type of EI, focused on the reduction of environmental negative externalities, the "Environmental impact reduction and safety improvement". The influence of environmental regulation to adopt environmental impact reduction and improvement safety innovation (approximately 34% of the firms – mean of dependent variable) are highly significant and positive, ranging between 0.2 p.p. and 0.8 p.p.. The interpretations of the control variables estimates are similar to those in Table 3, except for the Exporting firm variable that turned to be significantly and positively correlated to Environmental Impact reduction and Safety improvement innovation adoption (columns 2, 6 and 8).

The consistency of environmental regulation positive coefficients across the different types of EI and different models utilized is an important finding, and can be interpreted as reinforcement to the environmental inducement hypothesis. To a minor extent it also reinforces Porter's weak version (Porter and Van der Linde 1995). According to Porters' first component part, properly designed stringent environmental regulation would spur innovations[28].

Organizational environmental innovations regression results can be observed in Table 5. Once again the coefficients of explanatory variables are consistent across the four models estimated. Observing the results, it is clear that environmental regulation is less important to influence the average probability of adopting organizational environmental innovations, ranging from 0.002 p.p. to 0.5 p.p.. This finding is in line with the expected, since organizational innovations generally are voluntary measures adopted by the firm in order to complement technical EIs adopted.

The size of the firm and physical capital intensity coefficients are highly significant and positively correlated to organizational environmental innovation (as in Cole *et al* 2006). It is interesting to note that being a foreign owned firm increases the average probability of introducing organizational environmental innovations between 5.6 p.p.(column 6) and 6.1 p.p. (column 2), confirming that foreign owned firms are more likely to adopt organizational EI as pointed out by Albarnoz *et al* (2009). Being an Exporting firm also favours in average between 0.04 p.p. (column 8) to 5.3 p.p. (column 6) the adoption of organizational EI by the firm.

Table 6 presents results from the estimation of the determinants of pollution abatement expenditures. Since the pollution abatement investment is available only in three years (1997, 2002 and 2007), we constructed a three-year panel. We decided to use the pollution abatement investment variable as a dependent variable, instead of an explanatory variable (proxy to the stringency of environmental regulation) because we assumed pollution abatement investment as a proxy to environmental innovation.

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[28] For an analysis of the second component part of Porter hypothesis see Lucchesi et al (2014c).

The results in Table 6 show that environmental regulation is also important to invest in pollution abatement, registering highly significant and positive coefficients. Physical capital intensity and Exporting firm is positively correlated to pollution abatement investment. Interestingly, foreign ownership is negatively correlated to pollution abatement investment, suggesting that foreign owned firms tend to invest in more comprehensive solutions, in order to mitigate environmental damages, such as EIs.

6 Final Considerations

The determinants to environmental innovation in Brazilian manufacturing firms were shown to be consistent with the empirical literature on the topic. Environmental regulation registered an important role to influence the firms to adopt both technical and organizational EIs, although organizational EI are usually introduced voluntarily. Usually organizational EI are complement to technical EI and hence they often occur together. Thus, the results obtained in relation to the environmental regulation role confirm the environmental inducement hypothesis (also, these results reinforce the Porters' weak version).

However, environmental regulation is only part of the story. It is important to emphasize that, according to industrial economics literature (based in a Schumpeterian approach), there are other important determinants which influence the firm's innovative activities. In line with this approach, our results indicate that firms' size and physical capital intensity are also important variables. Large firms have numerous advantages to develop innovations such as stable financing funds and greater ability to deal with risky R&D activities. In turn, high physical capital intensity is associated with greater volumes of pollution and hence large abatement pressure, stimulating EIs.

Specifically related to developing countries innovative processes, our results confirm that foreign owned firms are significantly more likely to innovate "green" through capital embodied technology transfer and licensing agreements. On the other hand, export intensity registered highly significant and negative coefficients, contradicting international trade role in enhancing international monitoring and promoting domestic firms contact with more advanced technologies. Despite that, this result is in line with Marta *et al* (2001) and Del Rio *et al* (2011).

Future research should test the complementary effect of organizational EI as a determinant of technological EI. Unfortunately the data available does not permit to distinguish between end-of-pipe and clean technologies. It would also be interesting to investigate how technology sourcing affects environmental innovation adoption, since international licensing agreements play an important role in total patents granted in Brazil.

Finally, future research should consider the challenge to merge "green" patents INPI[29] data with PIA and PINTEC data. There are numerous difficulties concerning the utilization of the three databases. To cite a few, green patents classification is usually too embracing and it is very difficult to properly identify the patent depositor.

REFERENCES

Acemoglu, D. (2002). Directed Technical Change. **Review of Economic Studies**, 69, 781-810.

Albornoz, F.; Cole, M.; Elliot, R. and Ercolani, M. In search of environmental spillovers. **The world economy**, 2009.

Almeida, R. and Fernandes, A. M. (2008) Openness and technological innovations in developing countries: evidence from firm-level surveys. **Journal of Development Studies**, vol 44, No. 5: 701-727.

[29] Brazilian industrial property institute (INPI). Marta *et al* (2011) suggest a methodology to merge patents data to PIA and PINTEC data.

Anton, W. R. Q.; Deltas, G. and Khanna, M. (2004). Incentives for environmental self regulation and implications for environmental performance. **Journal of Environmental Economics and Management**, 48(1), 632-654.

Basant, R.; Commander, S.; Harrison, R. and Menezes-Filho, N. (2006) ICT Adoption and Productivity in Developing Countries: New Firm Level Evidence from Brazil and India. **IZA Discussion Paper**, No. 2294.

Bell, M. and Pavitt, K. (1997) Technological accumulation and industrial growth: contrasts between developed and developing countries. In: Archibugi, D. and Michie, J. (eds) **Technology, globalization and economic performance**. Cambridge University Press.

Brunnermeier, S. B. ans Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. **Journal of Environmental Economics and Management**, vol 45, 278-293.

Caroli, E. and Van Reenen, J. (2001). Skill biased organizational change? Evidence from a panel of British and French establishments. **Quarterly Journal of Economics**, 116: 1449-92.

Cohen, W. M. (2010). Fifty years of empirical studies of innovative activity and performance. In: Hall, B. H., Rosenberg, N. (eds), **Handbook of the Economics of Innovation**, vol 1, Elsevier Press: Amsterdam, 129-213.

Cole, M; Elliot, R. and Shimamoto, K. (2006). Globalization, firm-level characteristics and environmental management: a study of Japan. **Ecological Economics** n. 59.

Cole, M. A.; Elliot, R. J. R. and Shimamoto, K. (2005). Industrial characteristics, environmental regulations and air pollution: an analysis of the UK manufacturing sector. **Journal of Environmental Economics and Management**, vol 50, 121-143.

Del Rio, P.; Morán, M. A. T. and Albiñana, F. C. (2011). Analysing the determinants of environmental technology investments. A panel-data study of Spanish industrial sectors. **Journal of Cleaner Production**, 19, 1170-1179.

Demirel, P. and Kesidou, E. (2011) Stimulating different types of eco-innovation in the UK: Government policies and firm motivations. **Ecological Economics**, vol 70, 1546-1557.

Dosi, G. and Nelson, R. R. (2010) Technical change and industrial dynamics as evolutionary processes. In: Hall, B. H., Rosenberg, N. (eds), **Handbook of the Economics of Innovation**, vol 1, Elsevier Press: Amsterdam, 51-127.

Ferraz, C.; Seroa da Motta, R. (2001). Regulação, Mercado ou Pressão Social? Os Determinantes do Investimento Ambiental na Indústria. **Anais XXIX Encontro Nacional de Economia**, ANPEC.

Frondel, M.; Horbach, J.; Rennings, K. (2008) What triggers environmental management and innovation? Empirical evidence for Germany. Ecological Economics, vol 66, 153-160.

Frondel, M.; Horbach, J.; Rennings, K. (2007) End-of-pipe or cleaner production? An empirical comparison of environmental decisions across OECD countries. **Business Strategy and the Environment,** vol 16(8), 571-584.

Greening, L.A., Greene, D.L., Difiglio, C., (2000). Energy Efficiency and Consumption – the Rebound Effect: A Survey. **Energy Policy**, 28, 389– 401.

Hicks, J. (1932). **Theory of Wages.** Macmillan, London.

Horbach, J.; Rammer, C. and Rennings, K. (2012) Determinants of eco-innovations by type of environmental impact – The role of regulatory push pull, technology push and market pull. **Ecological Economics**, vol 78, 112-122.

Horbach, J. and Rennings, K. (2012). Environmental innovation and employment dynamics in different technology fields – an analysis based on the German Community Innovation Survey 2009. **ZEW Discussion Paper** No. 12-006, Centre for European Economic Research, Mannheim, Germany.

Jaffe, A. B.; Newell, R. G. and Stavins, R. N. (2003). Technology change and the environment. In: Mäler, K. G. and Vincent, J. R. (eds.), **Handbook of Environmental Economics**, vol 1, Elsevier Press: Amsterdam.

Jaffe, A. B. and Palmer, K. (1997). Environmental regulation and innovation: A panel data study. **The review of economics and Statistics**, vol 79, n.4: 610-619.

Khanna, M.; Deltas, G and Harrington, D. R. (2009) Adoption of pollution prevention techniques: the role of management systems and regulatory pressures. **Environmental Resource Economics**.

Khanna, M. and Anton, W. R. Q. (2002) Corporate environmental management: regulatory and market based pressures. **Land Economics**, 78 (4), 539-558.

Lucchesi, A.; Cole, M. A.; Elliot, R.J.R; Menezes-Filho, N. A.; (2014b) Environmental Innovation, skill demand and relative wages Brazilian manufacturing industry. Mimeo.

Lucchesi, A.; Cole, M. A.; Elliot, R.J.R; Menezes-Filho, N. A.; (2014c) Environmental Innovation and performance in Brazilian Firms. Mimeo.

Marta, F. S.; Carvalho, P. G. M., Silva, D. B. N. and Barcellos, F. C. (2011). Determinantes do valor do investimento em controle ambiental das indústrias brasileiras. **IV Encontro da Sociedade Brasileira de Economia Ecológica**.

Newell, R.G, Jaffe, A. B. and Stavins, R. N. (1999). The Induced Innovation Hypothesis and Energy-Saving Technological Change, **The Quarterly Journal of Economics**, 114: 941-975.

Organization for Economic Co-operation and Development (OECD) (2005) **OSLO Manual: proposed guidelines for collecting and interpreting technological innovation data**. Paris: OECD: Statistical Office of the European Communities – Eurostat.

Porter, M. and Van der Linde, C. (1995). Toward a new conception of the Environment-Competitiveness relationship. **Journal of Economic Perspectives**, vol 9, n.4: 97-118.

Queiroz, J. M. (2011). Determinantes da Inovação Ambiental: uma análise das estratégias das firmas da indústria de transformação brasileira. **Dissertação de mestrado**, Rio de Janeiro: IE / UFRJ.

Rennings, K.; Ziegler, A.; Ankele, K. and Hoffmann, E. (2006). The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. **Ecological Economics**, 57, 45-59.

Seroa da Motta, R. (2006). Analyzing the Environmental Performance of the Brazilian Industrial Sector. **Ecological Economics**, 57, 269-281.

Schumpeter, J. (1942). **Capitalism, Socialism and Democracy**. New York: Harper.

Sorrell, S. and Dimitropoulos, J. (2008) The Rebound Effect: Microeconomic Definitions, Limitations and Extensions. **Ecological Economics**, 65, 636-649.

Turner, K. and Hanley, N. (2011). Energy Efficiency, Rebound Effects and the Environmental Kuznets Curve. **Energy Economics**, 33, 709-720.

Wagner, M. (2009). Empirical influence of environmental management on innovation: Evidence from Europe. **Ecological Economics**, 66, 392-402.

Ziegler, A. and Nogareda, J. S. (2009). Environmental management systems and technological environmental innovations: Exploring the causal relationship. **Research Policy**, 38, 885-893.

ANNEXES:

Table 1 - Descriptive Statistics - Panel database

Variable	*Measurement*		*Number of obs.*	*Mean*	*Standard Deviation*
Dependent Variables:					
Environmental Innovation - at least one	*dummy variable*	*level*	32,894	0.43	0.49
Environmental Innovation - all	*dummy variable*	*level*	32,894	0.10	0.29
Environmental impact reduction and safety improvement	*dummy variable*	*level*	32,894	0.34	0.48
Environmental Management Techniques	*dummy variable*	*level*	25,813	0.41	0.49
Explanatory Variables:					
Environmental Regulation	*number of laws per state*	*3 year lagged*	32,894	5.3	4.2
Size of the Firm	*log (total employees)*	*level*	32,894	6.4	1.8
Exporting Firm	*dummy variable*	*level*	32,894	0.36	0.45
Foreign Ownership	*dummy variable*	*level*	32,894	0.22	0.42
Physical Capital Intensity	*log (capital stock/total employees)*	*level*	32,894	10.8	1.8

Notes: Panel database considers PINTECs 2000, 2003, 2005 and 2008 merged to PIAs 1998, 2001, 2003 and 2006

Table 2: Determinants of Technical Environmental Innovation (at least one)

Dependent Variable: Environmental Innovation - at least one

	Pooled OLS		OLS Fixed Effects		Pooled Logit *marginal effects*		Logit Fixed Effects *marginal effects*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Environmental Regulation	0.002*	0.004***	0.006***	0.006***	0.002***	0.002***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.00004)	(0.00004)	(0.00001)	(0.0001)
Size of the Firm		0.093***		0.023**		0.107***		0.011***
		(0.002)		(0.012)		(0.0001)		(0.001)
Exporting Firm		0.018***		-0.016		0.024***		-0.007***
		(0.007)		(0.015)		(0.0004)		(0.001)
Foreign Ownership		0.034***				0.019***		
		(0.007)				(0.0004)		
Physical Capital Intensity		0.018***		0.007		0.026***		0.006***
		(0.002)		(0.008)		(0.0001)		(0.0004)
Year Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industrial Sector Dummies	yes	yes	no	no	yes	yes	no	no
State Dummies	yes	yes	no	no	yes	yes	no	no
Observations	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*11,866*	*11,866*

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 3: Determinants of Technical Environmental Innovation (all)

Dependent Variable: Environmental Innovation - all

	Pooled OLS		OLS Fixed Effects		Pooled Logit *marginal effects*		Logit Fixed Effects *marginal effects*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Environmental Regulation	0.001	0.002**	0.002***	0.002***	0.001***	0.001***	0.008***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.00002)	(0.00001)	(0.0001)	(0.0001)
Size of the Firm		0.039***		-0.021***		0.026***		-0.082***
		(0.001)		(0.008)		(0.00004)		(0.001)
Exporting Firm		-0.0075*		0.017*		0.018***		0.097***
		(0.004)		(0.010)		(0.0001)		(0.003)
Foreign Ownership		0.044***				0.011***		
		(0.004)				(0.0001)		
Physical Capital Intensity		0.010***		0.004		0.011***		0.044***
		(0.001)		(0.005)		(0.00004)		(0.002)
Year Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industrial Sector Dummies	yes	yes	no	no	yes	yes	no	no
State Dummies	yes	yes	no	no	yes	yes	no	no
Observations	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*2,678*	*2,678*

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 4: Determinants of Technical Environmental Innovation (env. impact reduction and safety)

Dependent Variable: Environmental Impact reduction and Safety improvement

	Pooled OLS		OLS Fixed Effects		Pooled Logit *marginal effects*		Logit Fixed Effects *marginal effects*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Environmental Regulation	0.002*	0.003***	0.004***	0.004***	0.002***	0.002***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.00004	(0.00004)	(0.0001)	(0.0001)
Size of the Firm		0.079***		-0.0001		0.085***		-0.016***
		(0.002)		(0.011)		(0.0001)		(0.0005)
Exporting Firm		0.013**		0.002		0.027***		0.020***
		(0.006)		(0.015)		(0.0003)		(0.001)
Foreign Ownership		0.036***				0.019***		
		(0.007)				(0.0004)		
Physical Capital Intensity		0.018***		0.007		0.028***		0.010***
		(0.002)		(0.008)		(0.0001)		(0.0004)
Year Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industrial Sector Dummies	yes	yes	no	no	yes	yes	no	no
State Dummies	yes	yes	no	no	yes	yes	no	no
Observations	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*32,894*	*10,631*	*10,631*

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 5: Determinants of Organizational Environmental Innovation

Dependent Variable: Environmental Management Techniques

	Pooled OLS		OLS Fixed Effects		Pooled Logit *marginal effects*		Logit Fixed Effects *marginal effects*	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Environmental Regulation	0.001	0.002	0.004**	0.004**	-0.0001	-0.0001	0.005***	0.0002***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.0001)	(0.0001)	(0.0001)	(0.00001)
Size of the Firm		0.091***		0.065***		0.106***		0.002***
		(0.002)		(0.016)		(0.0001)		(0.0001)
Exporting Firm		0.047***		0.003		0.053***		0.0004***
		(0.007)		(0.020)		(0.0004)		(0.00004)
Foreign Ownership		0.061***				0.056***		
		(0.008)				(0.0004)		
Physical Capital Intensity		0.014***		0.031***		0.026***		0.002***
		(0.002)		(0.010)		(0.0001)		(0.0001)
Year Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Industrial Sector Dummies	yes	yes	no	no	yes	yes	no	no
State Dummies	yes	yes	no	no	yes	yes	no	no
Observations	*25,813*	*25,813*	*25,813*	*25,813*	*25,813*	*25,813*	*7,449*	*7,449*

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 6: Determinants of Pollution abatement investment

Dependent Variable: Pollution abatement investment (%)

	Pooled OLS		OLS Fixed Effects	
	(1)	(2)	(3)	(4)
Environmental Regulation	0.002**	0.002**	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Size of the Firm		0.005***		-0.009*
		(0.001)		(0.005)
Exporting Firm		0.006**		-0.010
		(0.003)		(0.007)
Foreign Ownership		-0.014***		
		(0.003)		
Physical Capital Intensity		0.007***		0.002
		(0.001)		(0.003)
Year Dummies	yes	yes	yes	yes
Industrial Sector Dummies	yes	yes	no	no
State Dummies	yes	yes	no	no
Observations	*23,290*	*23,290*	*23,290*	*23,290*

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A.1 - State environmental legislation: selected laws, decrees, resolutions, ordinances e regulatory instructions by year of publication

Region	State	Industrial Activities				Inspection / Monitoring / Sanction				Industrial effluents / industrial waste				Economic Instruments				Specific Industries				Total			
		1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005	1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005	1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005	1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005	1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005	1995 - 1997	1998 - 2000	2000 - 2002	2003 - 2005
Midwest	**DF** *(b)*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
	GO *(e)*	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0
	MT *(b)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS *(e)*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	2	0	0	1	4	2
	TO *(g)*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	2
Northeast	**AL** *(b)*	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	2
	BA *(f)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	CE *(g)*	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	2	1	0	0	3	1	1	1
	MA *(c)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PB *(b)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PE *(f)*	0	0	0	1	0	0	2	0	0	0	0	0	0	1	1	1	0	0	0	1	0	1	3	3
	PI *(d)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	RN *(d)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SE *(d)*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
North	**AC** *(d)*	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	3	1	1
	AP *(d)*	0	1	0	0	1	1	0	1	0	1	1	0	0	0	0	0	0	1	1	1	1	4	2	2
	AM *(f)*	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	2	1	1
	PA *(e)*	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3	1
	RO *(c)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0
	RR *(b)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Southeast	**ES** *(g)*	0	0	0	1	0	1	1	0	0	1	1	0	1	1	1	0	1	0	0	4	2	3	3	5
	MG *(f)*	0	0	0	2	0	1	2	1	0	0	1	0	0	0	0	0	0	0	1	3	0	1	4	6
	RJ *(e)*	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	3	2	1	2	4	3	1
	SP *(g)*	0	0	1	2	1	0	0	0	1	0	2	1	0	0	0	1	0	0	2	0	2	0	5	4
South	**PR** *(g)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	2	2	1	2	2	5
	RS *(d)*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1
	SC *(d)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NOTES: (b) includes only laws and decrees; (c) includes laws, decrees and ordinances; (d) includes laws, decrees and resolutions; (e) includes laws, decrees, resolutions and ordinances; (f) includes laws, decress, resolutions and normative instructions; (