Green regions and local firms' innovation

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Abstract

Technological innovation is essential to achieve simultaneously economic, environmental and social goals (i.e. the *green growth)*. Indeed, many studies found that environmental innovation spurs overall innovation. However, this topic has not been investigated by taking into account the geographical context. Therefore, our paper seeks to investigate whether 'green regions', with an increased public and private commitment in environmental issues, are related to innovation of local firms. Using data on Spanish manufacturing firms and regions, we find that environmental technologies (especially in green energy), environmental investments, and environmental management at the level of regions are positively associated to local firms' innovation.

Keywords: innovation; region; firm; green patents; environment
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1 Introduction

It is widely recognized that economic growth cannot be pursued by ignoring environmental and social concerns. This concept is at the basis of the so-called *green growth*, which is the idea that economic, environmental and social goals could be achieved simultaneously (Fankhauser et al., 2013). Technological innovation, which is the main engine of economic growth, is essential to meet a green growth. Innovation makes existing industries more environmental sustainable while at the same time promotes new industries and a diversified economy (Costantini et al., 2013; Markard et al., 2012; Porter & Van der Linde, 1995). Innovation may break dependence on established ways of doing things and open up opportunities for new raw materials (e.g. in the field of renewable energy) and auxiliary services (e.g. engineering support for green buildings), but also promote new products and services that may cohabit with existing ones in a more diversified economy (e.g. oil-based plastics together with biodegradable plastics).

The environmental innovation (EI) literature acknowledges that EI could spur overall innovation capacity of firms, industries, and countries, enhancing their competitiveness (Lanoie et al., 2011). This literature suggests that the actions to reduce the environmental impact of economic activities could boost competitiveness through innovation at the country, industry or firm-level. Within the EI literature, studies on the drivers of EI rarely introduce spatial elements (Antonioli et al., 2016; Cainelli et al., 2012, 2015; Ghisetti & Quatraro, 2013; Horbach, 2014) and they do not investigate the linkages to overall innovation, while the geographical context is more openly incorporated in the studies on the effects of EI (e.g. Costantini et al., 2013).

Space is a crucial concept in innovation studies. Despite innovation occurs at the firm-level, the spatial context influences and constraints the innovation capacity of firms (Boschma & Martin, 2007; Iammarino, 2005). Studies that have tried to reconcile the micro-level and the aggregate-level identify which regional factors affect firm performance (Czarnitzki &

Hottenrott, 2009; López-Bazo & Motellón, 2018; Naz et al., 2015; Smit et al., 2015; Srholec, 2010). Among these factors, however, whether a major change (such as the 'greening' of the region, which has the potential to transform not just one sector but the entire economy (Fankhauser et al., 2013)), is a fertile ground for local firms' innovation has been neglected.

We intend to fill this gap by investigating whether certain characteristics of being a green region are associated to firm innovation. While taking into account firm-level determinants of innovation, we consider both traditional inputs to regional knowledge production (Acs et al., 2002) and indicators of green regions identified along three dimensions, drawing on established determinants of EI. The first is purely related to the technologies that are at the base of the transition to more environmentally-friendly mode of production and consumption (Ghisetti & Quatraro, 2017; Noailly & Shestalova, 2017; Popp & Newell, 2012). The second one is about the regulation landscape, extensively recognized as a major driver of EI (Porter & Van der Linde, 1995). Thirdly, we consider the adoption of new organization forms to manage the environmentally-related processes (Cuerva et al., 2014; Horbach, 2008; Rehfeld et al., 2007; Rennings et al., 2006).

We combine firm-level data from a Spanish survey on the manufacturing sector (Survey on Business Strategies, ESEE), and regional-level data. In order to treat the multi-level structure of our dataset, we employ a 'two-stage' procedure (Angrist & Pischke, 2009, Chapter 8), in which firstly we estimate the determinants of firm-level innovation (product and process, separately) with region-by-year effects and secondly we regress these effects on regional characteristics, included our key indicators proxying for how 'green' a region is. Our main results point out that the technological specialization in green energy patents of the regions is strongly associated to local firms' process innovation, while environmental protection investments in the regions are strongly linked to product innovation of local firms. A weaker but still significant relation is found for environmental management and process or product innovation.

The paper is organized as follows. Section 2 presents the theoretical background and our expectations. Section 3 explains the methodology and the data. Results are shown in Section 4, and finally conclusions are drawn in Section 5.

2 Theoretical background and propositions

The geography of innovation literature has embraced the view that the aggregate outcome is also the results of firms' behaviour. Firm innovation is determined by internal and external factors (Jaffe et al., 1993; Vega-Jurado et al., 2009). Firms do not carry out innovation activities in isolation, but their innovative output is the result of interactions with a set of actors, such as users and suppliers, research centres and universities, and financial institutions that are localised nearby (Bathelt et al. 2004). The interaction with these actors is often voluntary, as firms may actively engage in various forms of collaboration. However, the fact of being placed in a certain location exposes also to involuntary knowledge spillovers, in terms of the mobility of workers, participation to business associations, or simply by informal contacts facilitated by proximity. Indeed, at an aggregate level, empirical studies (Jaffe et al., 1993) highlight that knowledge produced by a firm is only partially appropriated by the producer, whereas part of such knowledge spills over to other firms and institutions.

Within the local knowledge spillovers literature it is widely recognized that i) knowledge spills over more easily with physically close actors than if located far apart and ii) given the informal nature of such spillovers, little effort is needed to benefit from them since flows are more or less automatically received thanks to proximity (Malmberg and Maskell 2006). These ideas take us to the concept of local buzz (Bathelt et al. 2004) consisting of information created by numerous face-to-face contacts, the application of the same interpretative schemes of new knowledge, a similar experience with a particular set of problem-solving techniques, and the shared cultural traditions that make interaction less costly.

In the geography of innovation literature, a body of research has tried to connect the micro-level and the aggregate level to assess the relative role in firm innovation. Part of these studies suggest that the firm heterogeneity plays the major role, while regional factors are negligible (Smit et al., 2015). Instead, other recent studies conclude that local factors matter a lot too, like for example R&D expenditures, technology transfer and networking, human capital and proximity to suppliers, the quality of the regional innovation system, some social characteristics, and agglomeration externalities (Czarnitzki & Hottenrott, 2009; López-Bazo & Motellón, 2018; Naz et al., 2015; Srholec, 2010).

One aspect that has been neglected in these studies is how some major change at the meso level (i.e. the region) is related to change at the bottom (Iammarino, 2005). The role of change is central in evolutionary economics, according to which the economy is driven by processes of creative destruction and creative accumulation (Malerba & Orsenigo, 1995; Nelson & Winter, 1982). Change is rooted in the firms' behaviours, which use their capabilities (routines) to adapt and survive in a dynamic environment. Such change is influenced and constrained by space (Boschma & Lambooy, 1999; Boschma & Martin, 2007; Iammarino, 2005; Lambooy, 2005). Indeed, locations provide the opportunities, challenges and inputs that the firms can benefit from, and shape the paths of possible outcomes because of historical contingency. At the same time, firms themselves shape the external space in accordance to their needs (knowledge, skills, capital) (Boschma & Lambooy, 1999). Firms' success and regional performance are mutually dependent and, rather than a unilateral causality link, this process can be seen as co-evolutionary (Iammarino, 2005).

Following the recent debate on whether green growth could be considered a new technological revolution, many scholars observe that green growth has the potential to transform not just one sector but the entire economy (e.g. Fankhauser et al., 2013). Green growth could produce an economy-wide transformation, rather than merely the expansion of the environmental goods and services sector. Therefore, it is a relevant issue to understand whether this change is associated to a virtuous circle of knowledge creation, intended as a co-evolutionary process in which the interdependence between aggregated outcomes and actors is based on a ‘feedback’ mechanism (Boschma & Lambooy, 1999): the context provides the environmental-related inputs and firms react with the creation of new variety, and at the same time firms participate in the formation of those environmental-related inputs.

Different environmental issues could be the expression of such major change. We consider, firstly, the change in technology (Fankhauser et al., 2013), then the regulatory landscape (Porter & Van der Linde, 1995), and thirdly, the organizational change (Rennings et al., 2006).

The mechanism through which a change in one of the environmental issues at the regional level can be associated to local firm innovation is knowledge spillovers. As discussed in Rennings (2000), EIs have a “double externality” effect: (1) the reduction of environmental externalities, and (2) the typical R&D spillover effect (Jaffe et al., 1993). Therefore, we expect that the change at the meso-level could trigger specific EI and/or other types of innovation in local firms. Hence, our general hypothesis is that a green region constitutes a fertile ground for local innovation.

2.1 Knowledge in environmental technologies

One the most used indicator of a change towards a green economy is technological innovation, as indicated by patents, which measures how new products are likely to replace conventional products and processes (Fankhauser et al., 2013). Green patents grew faster than total patents during the 2000s, especially in fields such as renewable energy, electric and hybrid vehicles, energy efficiency in building and lighting (OECD, 2011). Hence, this suggests that firms are putting a lot of efforts in the green-tech race, whatever the underlying motives are (Berrone et al., 2013).

EI in the form of patents may be associated to other set of innovation, not strictly in the environmental domain. EI makes firms more innovative, and is correlated to different measures of performance (Lanoie et al., 2011). Accordingly, the agents involved in developing environmental technologies are part of a network of innovative partners and co-locate with some of them (Galdeano-Gómez & Céspedes-Lorente, 2008). Indeed, environmental innovative firms have a higher propensity to cooperate on innovation with external partners (De Marchi, 2012). The new shared knowledge could be related to environmental technologies, or being more generally about new technologies, processes or products. For example, automotive firms that have decided to develop electric cars, could design smaller and lighter vehicles, requiring their local suppliers to come up with new innovative solutions. This way, an innovation in the environmental domain needs new products and materials that do not necessarily fall into the environmental field.

We may expect a different intensity of the relation between green patents, on one hand, and product or process innovation on the other, depending on the type of environmental technologies in which the region patents more. Among green technologies, alternative energy patents seem to produce more knowledge spillovers than other patents (Popp & Newell, 2012). They are more "general" than other patents, hence a broader set of actors is influenced by such knowledge (Popp & Newell, 2012), especially because they are used as input to production in almost all industries. Noailly and Shestalova (2017) find that energy patents have high knowledge spillovers, and that, in particular, storage and solar technologies find applications outside the field of power generation. The applications of a new technology that uses energy more efficiently tend to be used in firm production processes. It constitutes a process innovation. This could spur further process innovation in the same firm or other firms located nearby. Process innovation spillovers are generally found correlated to firms' efficiency (Ornaghi, 2006). For example, a firm that has patented a new system to fuel a certain phase of its production process by using solar energy is already introducing a process innovation; also, this could lead to further changes in the production process, perhaps not directly linked to the solar energy but that constitute an innovation. Then, these new waves of innovation could cause further innovation along the value chain in the proximity of the firm (Costantini et al., 2013; Ghisetti & Quatraro, 2017), or simply become new knowledge that spill over through worker mobility or collaboration with other firms. Hence, we posit that:

> *Knowledge in environmental technologies at the regional level that tends to reduce the use of energy is positively associated to process innovation of local firms.*

Many technologies are components of other goods and services. When such new goods or services – invented locally - are adopted by a local firm, this can stimulate further product innovation by the same firm or other related organizations. Indeed, product innovation spillovers seems more likely to affect firms' demand (Ornaghi, 2006). Different scholars have evaluated the transmissions of the benefits of environmentally-related innovation along the value chain and in the same sector. Ghisetti and Quatraro (2017) find that the introduction of green technologies has positive effects on firm environmental productivity; this applies when the green technology is introduced in the same sector, but also in vertically related sectors. Cainelli and Mazzanti (2013) found that, in few cases, EI in services is stimulated by the those in related manufacturing sectors. This could happen because of imitation (e.g. the new good has high profit margins and other firms want to come up with something similar), or adaption to the new standard by suppliers (e.g. if a firm invents a biodegradable plastic component, then the suppliers need to adapt the existing components to the new one, doing an effort that can lead to product innovation). Or in the case of automotive firms, we may find vehicles that use new sources of energy (e.g. electricity, hydrogen) or a combination of old and new sources (e.g. hybrid vehicles) and, most of the innovations do not refer to the entire new vehicles, but to components, such as engines and braking systems. In this latter case, it is very likely that the introduction of new components is linked to innovation in related components (namely, in product innovation), to be produced by the same firm or by its network in the vicinity. Hence, this reasoning leads us to hypothesize that:

> *Knowledge in environmental technologies at the regional level that is more likely to be incorporated in new components or final products is positively associated to product innovation of local firms.*

2.2 Environmental protection expenditures

Policy intervention is crucial in the transition to more environmentally sustainable economy (Markard et al., 2012), because the established mode of production and consumption change slowly, and there may not be sufficient pure market incentives to go green (Porter & Van der Linde, 1995). Environmental regulations and standards have been found to be effective instruments to spur EI (Lanoie et al., 2011; Porter & Van der Linde, 1995).

The link between environmental regulation and innovation, although strongly corroborated by the empirical literature (for a review e.g. Barbieri et al., 2016; D’Agostino, 2015), depends on the type of policy instrument. End-of-pipe solutions (such as external recycling, treatment and recovery of already formed contaminants) seem less effective to spur innovation than more flexible and market-based instruments (such as tax-structure shifts, tradable permits, rewards for cleaner practices, and stiff pollution penalties), and pollution prevention in general (specifically waste and source reduction) (Lanoie et al., 2011). In this sense, on the one hand, environmental protection expenditures of the private sector could be seen as a mere compliance to the law, namely a cost that the firm has to sustain without expecting any benefit from it. For this purpose, Leiter et al. (2011) use current expenditures on environmental protection as a proxy for stringent environmental regulation, together with revenues from environmental taxes. On the other hand, environmental protection expenditures could be seen as an opportunity to extract value in the future, if in the form of an investment (Lanoie et al., 2008; Leiter et al., 2011). Indeed, many scholars identify a positive link between such investments and EI innovation (e.g. Brunnermeier & Cohen, 2003). Therefore, we expect that regions where environmental protection expenditures in the form of investment are high, are generating innovation to accommodate to this regulation and, through the channels described above, knowledge spillovers. This is associated to a higher probability of local firms to introduce innovation.

An investment in capital goods (such as resource-efficient machineries) or intangibles (as software that monitors emissions) enters the production phase. In general, although process innovations are crucial to boost productivity, cash flows to repay investments are mainly obtained by selling (innovative) products, so that firms are more prone to undertake an environment protection investment if this could be translated in a new product; and a new product goes together with innovation in the suppliers of components to such new product. At the same time, environmental investments improve the production method of firms, generating process innovation in the firm making the investments, in their network of suppliers that need to adjust to the new production, and on other firms that eventually are willing to adopt the same environmental technologies. However, we expect that the additional demand generated from new environmental equipment is highly associated to local firm product innovation (especially in the suppliers). Indeed, technology diffusion of product innovation seems larger than the one of process innovation (Ornaghi, 2006), and this may be one of those cases. In a comparison between the determinants of environmental process and product innovation, Cleff and Rennings (1999) observe that process EI are less affected by market strategies, as firms "earn money by selling products, not processes" (p. 201). This suggests that strong market incentives (for examples the ones faced by suppliers for the increase of demand of new environmental technologies) are not major determinants of process innovation. Following this reasoning we can state that:

Environmental protection expenditures in the region in the form of investment is positively associated to the product innovation of local firms.

2.3 Environmental management tools

A third regional characteristic related to environmental issues is the introduction of environmental management systems (EMS). Firms and organizations that are willing to be more resource-efficient and give an environmentally-friendly image to the outside could also make environmental organizational changes. There are voluntary programmes that help to monitor the organization in order to identify which areas to intervene to accomplish certain environmental goals (e.g. reducing emissions, use less energy, use alternative raw materials, etc.). The empirical literature has used different measures of EMS (Barbieri et al., 2016). In the European context, there are mainly two tools: the European Commission's Eco Management and Audit Scheme (EMAS) and the International Organization for Standardization's ISO14001 standard. Such programmes have been found to positively impact EI and economic performance (Cuerva et al., 2014; Horbach, 2008; Rehfeld et al., 2007; Rennings et al., 2006; Ruigrok et al., 2007; Wagner, 2008; Ziegler & Seijas Nogareda, 2009). For example, Horbach (2008) finds a positive effect of EMS not only on EI but also on overall innovation. Therefore, similarly to the mechanism of innovation-inducement and knowledge spillovers we have highlighted above, we expect that such innovation could be diffused to the entire region, increasing the probability of other firms to be engaged in innovation.

The general literature on the linkage between EMS and EI find a positive effect, but the evidence is mixed with regard to the impact on product or process innovation. Rehfeld et al. (2007) find that having introduced either an EMAS or an ISO14001 certification positively impact product EI, while Wagner (2007) identifies a positive effect of EMS on process EI and no effect for product EI. Focusing only on EMAS-certified firms, Rennings et al. (2006) find that process EI are particularly affected by the maturity of the EMS in the firm.

From a conceptual point of view, we expect that the knowledge created while adopting environmental management tools could be used in production processes (for example, a new process that uses less energy), or as a new component or product (for example, a product that uses less packaging or recyclable materials). Here, since environmental management tools are applied in the production process, but also on the characteristics of final goods or services produced, we do not formulate any specific expectation on the relation with process or product innovation, as suggested by the mixed empirical evidence (Rehfeld et al., 2007; Rennings et al., 2006; Wagner, 2007). We posit that:

Environmental management tools adopted in the regions are positively associated to both product and process innovation of local firms.

3 Methodology and data

3.1 Methodology

The regional knowledge production function approach (Griliches, 1979) believes that knowledge –especially that of tacit nature – is difficult to appropriate in its totality by its producer and therefore may spill over to third parties, on the one hand; and on the other, this approach highlights that knowledge diffusive patterns are subjected to strong spatial decays (Jaffe et al., 1993). These two ideas have produced a prosperous literature declaring that, by being co-located in the same physical space, agents are subjected to a constant amount of information flows and knowledge transfers that take place unceasingly in both organized and accidental meetings (Bathelt et al. 2004).

Some criticisms to this logic stemmed since the path from R&D efforts to innovation is not always straightforward. Rodriguez-Pose (1999), among others, signals that different social and institutional local conditions may lead to important differences in the returns to innovation. Indeed, countries and regions differ in their socioeconomic composition, which may justify a substantial part of their heterogeneity in innovation performance. For the sake of this paper, we are going to control for environmental regional features that may act as precondition for the innovation activity. Thus, our model of interest is:

$$Y_{irt} = a + \boldsymbol{X}_{irt}\gamma + \boldsymbol{Z}_{rt}\beta + \varepsilon_{irt}$$

where Y_{irt} is the dependent variable, a proxy of innovation, for firm *i* in region *r* at time *t*. $\boldsymbol{X}_{irt}$ are characteristics of the firm and $\boldsymbol{Z}_{rt}$ are characteristics of the region where the firm is located. ε_{irt} is an error term. Following our theoretical discussion, it is reasonable to assume that firms located in the same region are exposed to the same institutional and economic background. This correlation within regions is often modelled assuming that the residual ε_{irt} has a group structure (Angrist & Pischke, 2009):

$$\varepsilon_{irt} = v_{rt} + \eta_{irt}$$

where v_{rt} is a random component specific to region r, and η_{irt} is a mean-zero firm-level component. The within-group correlation when using micro-data with regional-level covariates can cause a bias of the standard errors, leading to overestimate the importance of regional characteristics on firm-level innovation (Moulton, 1990).

To tackle this problem, we employ a 'two-stage' procedure (Angrist & Pischke, 2009), widely applied in empirical studies on the relationship between individual wages and regional or provincial unemployment rates (Ammermuller et al., 2010; Peng & Kang, 2017).

In the first step, firm innovation is regressed on micro-characteristics and region-by-year fixed effects that are proxies for regional-level factors:

$$Y_{irt} = a + \boldsymbol{X}_{irt}\gamma + \sum_{r=1}^{17}\sum_{t=2004}^{2013} \boldsymbol{\mu}_{rt}\boldsymbol{D}_{rt} + \eta_{irt}$$

The group effects μ are coefficients on a full set of region-by-year dummies $\boldsymbol{D}_{rt}$. The estimated $\widehat{\mu_{rt}}$ are group means adjusted for the effect of the firm-level variables $\boldsymbol{X}_{irt}$. The random-effects logit estimator is used in this first step.

In the second step, we regress the estimated group effects on group-level variables (regions, in our case):

$$\widehat{\mu_{rt}} = b + \boldsymbol{Z}_{rt}\beta + v_{rt}$$

The firm level estimation is carried out with a random-effects model whereas for the regional one we use fixed-effects. This is so because we follow the distinction between the fixed and the random effects models as a difference between a conditional and an unconditional inference (Baltagi, 2005). When the individual effects are fixed, our inference is conditioned to the individuals (or cross-section observations) of our sample. The conditional inference is probably accurate if the individuals for which we have data are not a random sample extracted from a higher population but the whole population. This is the case in the regional regression in the second step. On the contrary, if the individuals are a random sample from a higher population, and we are interested in obtaining inference for the whole population, then the unconditional inference that is implicit in the error components approximation, that is, the random-effects model, seems more accurate. This is the case in the firm level regression in the first step.[1]

3.2 Data

We exploit the original information on the location of firms to test whether regional environmental features are associated to higher innovation capacity of local firms. In the first step, we use micro-data that are drawn from the Survey on Business Strategies (ESEE), a panel of manufacturing firms located in Spain. Data are collected by the Ministry of Industry and Energy in collaboration with the SEPI Foundation. About 1800 firms have been surveyed since 1990 each year, using a questionnaire that includes information on a wide range of topics (innovative activities, financial data, market and product characteristics, among others). It covers firms with 10 or more employees. All firms with more than 200 employees are included, while firms employing between 10 and 200 workers are representative of the population of reference. Our final sample entails 5304 firms in the years 2004-2013.

The dependent variable used in the first step is binary, indicating whether the firm has introduced an innovation in the given fiscal year or not. In particular, we use two different dependent variables: product innovation (*PROD*) and process innovation (*PROC*). Table 1 presents the number and percentage of firms introducing innovation by year, showing that process innovation concerns a higher number of firms than product innovation throughout the period. On average, product innovation firms constitute about one-fifth of the total, with a decreasing trend over the period (except an increase in 2009-2010) and in 2013 they constitute 16.1% of the total, against the value of 21.83% in 2004. Instead, process innovative firms (that

[1] In addition to that, in the first step we cannot use fixed-effects because many observations have zero value in the dependent variable in all years, which leads the fixed-effect model to drop such observations. Also, in the second stage, we test fixed-effects versus random-effects, finding support for the former one.

on average are about thirty percent of the total) show an increasing trend up to 2007 (35.27%) and a slight decreasing trend up to 2013 (31.19%, albeit higher than in 2004).

[TABLE 1 here]

We control for a set of firm-level characteristics, as suggested by the innovation literature that uses survey-data. We control for firm size measured as the number of employees (*size*) and we also introduce its squared term (*size2*) to take into account nonlinearities, both transformed in natural logarithms. We introduce the share of internal R&D expenditures on turnover (*in-house R&D intensity*) as a proxy for a firm's absorptive capacity (Triguero & Córcoles, 2013). In addition, we use a set of dummies accounting for whether the firm conducted internal R&D activities continuously (*permanent R&D*) (Raymond et al., 2010), whether it has a *foreign* ownership of more than 50%, whether the firm exports or not (*export*) and whether it has access to R&D funded by public government (*public R&D funding*). We also account for the dynamism of the most important market in which the firm operates (i.e. *expansive market*, *stable market*, and - as benchmark category – *market in decline*, as declared by the firm itself) (Triguero & Córcoles, 2013). In line with the literature that recognizes the importance of external sources of knowledge, we introduce a binary indicator for R&D *cooperation* (Nieto & Santamaría, 2010) in case the firm declares having technological cooperation agreements with other firms or institutions. Finally, we expect firms operating in high technology industries to be more innovative than the ones in low technology industries. The variable *high-tech sectors* is a dummy that takes the value 1 if the firm belongs to a high technology industry (Valle et al., 2015). All the covariates are 1-year lagged, except high-tech sectors.

For the second step, we collect data on the 17 Spanish NUTS2 regions for the period 2004-2013 from different sources. The dependent variable is the estimated group effects obtained from the first step. Our regression in this second step includes several proxies of being a 'green region': knowledge base in environmental technologies, environmental protection expenditures, and environmental management.

For environmental technologies, we use green patent applications: *green patents*, *energy patents* (i.e. alternative energy production, energy conservation, nuclear power generation), *transportation patents*, and *other green patents* (i.e. waste management, agriculture and forestry, administrative, regulatory, or design aspects), and the Revealed Technological Advantage (RTA) indexes built on each of them (for further details see methodological note on Appendix A, section 1).

For the indicators of regulation landscape, we use environmental protection expenditures, which is provided into two components: current expenditures and investments (for further details see methodological note on Appendix A, section 2). For each of the two measures, we compute the ratio between the values in the manufacturing sectors and GDP (*EEX* for current expenditures, and *EINV* for investments) in each region for the latest period for which data are available (i.e. 2008-2013). *EEX* indicates a cost sustained by the firms to maintain their environmental protection activities. This commitment could be due to a technological choice made by the firm (e.g. building smaller electronic devices requires more energy), to the natural resource endowments and industrial specialization of the region (e.g. to generate electricity, regions might rely on burning fossil fuels or they might use alternative sources such as wind, solar, or hydroelectric power, depending on the local availability) or to a specific regulation imposed by the government. Environmental protection expenditures has been used as a measure of regulation stringency (Brunnermeier & Cohen, 2003; Leiter et al., 2011), which at the same time imposes a cost of compliance to the firms and also opens up new opportunities (Porter & Van der Linde, 1995). Similarly to *EEX*, *EINV* indicates that the investment could be induced by external forces (e.g. availability of resources or regulation), but also that it could be voluntary (e.g. the will to reduce the impact on the environment). However, differently than *EEX*, *EINV* indicates a long-term commitment to either prevent or clean-up pollution that requires the introduction of equipment new to the firms. This could stimulate other innovations in the firms, as the firms might discover cheaper or more effective production processes, or even introduce new products that require less energy or raw materials whose idea has been inspired by the initial investment. In their seminal work on environmental regulation and innovation, Porter and van der Linde (1995) report several anecdotes on how the compliance to a more stringent regulation has led to new processes or products that the firms are willing to develop beyond the regulation' requirements. At the aggregated level, innovation resulting from high environmental investments could spill over to other firms in the regions.

For the indicator of environmental management, we collect information on the adoption of the EMAS by organizations (enterprises or institutions) in Spanish regions.[2] Organizations adhere voluntarily to this scheme to evaluate, report, and improve their environmental performance. The introduction of environmental management tools has been found positively correlated to EI at the firm-level (e.g. Rennings et al., 2006). At the aggregated level, this innovation could spill over to other firms in the regions. The variable *EMAS* is calculated as 2-year average to smooth peaks.

The variables on environmental technologies are 2-year lagged, as it is required more time from patent application to the public availability and diffusion of its content. Similarly, *EEX* and *EINV* are 2-year lagged, as it might take time from the initial expenditures to spur innovation and then knowledge spillovers to the entire region.

As control variables in the second step, we introduce a set of variables as in the tradition of the regional knowledge production function (Jaffe et al., 1993). Data are drawn from Eurostat. We introduce *business R&D per GDP* and *public R&D per GDP* to control for

[2] http://ec.europa.eu/environment/emas/register/

knowledge inputs of the private and public (government and high education) sectors, respectively (Acs et al., 2002). The industrial specialization is accounted for by the employment share in manufacturing (*manufacturing specialization*) (Marrocu et al., 2013). We also control for regional size and agglomeration economies with population density (inhabitants per square kilometre, *pop. density*) (Miguélez et al., 2011) and its squared term for non-linearity (*pop. density 2*). Control variables in the second step are 1-year lagged.

4 Results

We present the results for the second step. A correlation matrix and the estimates for the first step are given in Appendix Table A.1 and Appendix Table A.2, respectively. The correlation table for the second step is in Appendix Table B.1.

Table 2 shows the estimations of the fixed-effect panel at regional-level, where the dependent variables are the estimated group effects of the first step, for product and process innovation separately. Models 1-8 present the results for green patents and their different groups, taken as shares on total regional patents. *Green patents* (Models 1-2) are not statistically significant and neither any of their different groups, with the exception of *Energy patents* which has a positive and statistically significant coefficient for process innovation (Model 4, at $p < 0.10$). The result for green energy technologies is reinforced if we consider the adjusted RTA (Model 10, at $p < 0.01$). In addition, the relative advantage in green transportation patents (i.e. *RTA Transport. patents*) turns out positive and marginally statistically significant for product innovation (Model 11, at $p < 0.10$). These results point out that a region more engaged in environmental technologies in general does not necessarily produce knowledge spillovers from which local firms could benefit as for the generation of innovations.

However, specific environmental technologies have this power. In particular, it seems that energy patents are particularly apt for this role, in line with previous studies (Noailly &

Shestalova, 2017; Popp & Newell, 2012). In this category, we find technologies that have the direct purpose to find alternative ways to produce energy than traditional fossil-based sources, as well as new methods of energy conservations. These are two key fields in which technology could help green growth, namely by finding new environmental-sustainable energy sources and at the same time working on energy-efficiency. These are also fields that could stimulate further innovation more directly, as in the example given in section 2 of the firm patenting a new system to fuel a certain phase of its production process by using solar energy, which could lead to further changes in the production process, perhaps not directly linked to the solar energy. It is not surprisingly that energy patents are not related to product innovation, as energy is considered a production factor (Ornaghi, 2006), so any improvement in this sense is more likely is be associated to the production process, rather than a final product, unless we consider firms operating in sectors producing final goods that incorporate these new technologies (e.g. producers of solar panels).

Similarly to energy patents, it seems that also transportation patents are linked to firm innovation when the region has a comparative advantage in these technologies, although in this case to new products. In this category of technologies, we find all types of vehicles that use new sources of energy (e.g. electricity, hydrogen) or a combination of old and new sources (e.g. hybrid vehicles). As commented in the review of literature, although these types of patents could regard entire new vehicles, most of the technologies refer to components (engines, braking systems, etc.). The introduction of these new components may be coupled with innovation in related components to be produced by the same firm or by its network of suppliers or clients which tend to be located closely. Our results are in line with studies that observe how the benefits of EI are transmitted through the value chain and within the industry (Cainelli & Mazzanti, 2013; Ghisetti & Quatraro, 2017).

With regards to the control variables, *business R&D per GDP* is consistently positive and statistically significant ($p < 0.01$) for all specifications for process innovation, while unimportant for product innovation. Within the regional knowledge production function framework, industrial R&D is found strongly correlated to innovation output (Acs et al., 2002). Probably, in our case the stronger link between business research and process innovation (and not product) could be due to the fact that a higher share of firms in our sample carries out process innovations. *Public R&D per GDP* is consistently negative and marginally statistically significant ($p < 0.10$) for all specifications for product innovation (except in Model 1), while unimportant for process innovation. While the empirical evidence generally points out that university and government research are important determinant of firms' innovation, in our case the regions with the highest public R&D intensity are not only the richest (such as Catalonia and Comunidad de Madrid) but also backward regions with smaller economies (such as Cantabria and Extremadura) in which public R&D spending (although smaller in absolute number than in other regions) drives upwards the R&D intensity because of a low denominator. Therefore, in these latter regions, despite public expenditure in research constitutes a relatively high share of the economy, the expected knowledge spillovers to firms' innovation do not seem to materialize, or not yet. Hence, regions with high public R&D intensity are negatively correlated to the capacity of firms to introduce innovation. Such relation is particularly strong for product innovation, perhaps for the nature of our sample, where firms, if they do innovation, are more likely to carry out process innovation than product innovation. Therefore, the disadvantage of being in a region with a high weight of public research is particularly strong for the firms struggling to introduce new products.

[TABLE 2 here]

Table 3 shows the estimations of the second step with the environmental protection expenditures as key independent variables. Models 15-16 include the variable on current expenditures (*EEX*), while Models 17-18 the variable on investments (*EINV*). While *EEX* turns negative and marginally statistically significant ($p < 0.10$) for product and for process innovation, *EINV* has a positive and statistically significant coefficient for product innovation ($p < 0.01$). In line with the definition, current expenditures are an operating cost deriving from those activities of the firms that pollute or cause any other damage to the environment. Accordingly, regions that register high current expenditures on GDP are more likely to have firms less concerned with a radical change of paradigm and want just to internalize the cost of polluting. This could be caused by specific choices of local firms, or industrial specialization in sectors that are highly polluting by nature. Contrary to current expenditures, investments require the introduction of new installations or equipment, or even intangible goods, which are all types of innovation new to the firm that could accompany innovation in the same firms and in the firms in the proximity. We only obtain this result for product innovation, suggesting that, even though environmental investments could be associated to both product and process innovation, local knowledge spillovers affect product innovation. This is line with the evidence that technology diffusion of product innovation seems larger than the one of process innovation (Ornaghi, 2006). This result could also be driven by the fact that aggregated demand of new environmentally-friendly equipment stimulates product innovation more heavily, while the additional effects on process innovation are negligible. This result is also in line with the findings that product EI are more likely to be influenced by market factors (Cleff & Rennings, 1999).

With regards to the control variables, neither *business R&D per GDP* nor *public R&D per GDP* are statistically significant in any specifications. *Manufacturing specialization* is statistically significant for process innovation. Instead, the proxies for agglomeration economies are statistically significant for product innovation: *pop. density* is positive and its squared terms is negative, hence suggesting that until a certain threshold, agglomeration is related to product innovation.

[TABLE 3 here]

Table 4 shows the second-step estimations for environmental management as key explanatory variable (Models 19-20). We obtain marginally statistically significant coefficients for product and process innovation (at $p < 0.10$). This suggests that the adoption of EMAS in the region is related to a situation for which firms and organizations, once they start to monitor themselves about their environmental practices, stimulate new ideas and improvements that eventually translate in innovation. Again, here the presence of more innovative firms in the region could be correlated to firms themselves introducing EMAS, or to knowledge spillover effects from interacting with firms and organizations that have introduced such tool in the region. However, it needs to be noted that this result is weak, perhaps because of the still low number of new organizations adhering to the EMAS programme in each region.

With regards to the control variables, similarly to the estimations with the indicators of environmental technologies, we observe that *business R&D per GDP* is positive and significant for process innovation (although with a weaker level of significance) and *public R&D per GDP* is negative and significant for product innovation. The remaining controls *manufacturing specialization*, *pop. density* and *pop. density 2* are not significant.

[TABLE 4 here]

4.1 Robustness checks

To corroborate our main results, we run a number of robustness checks. Firstly, we re-run the main estimation without the controls that – despite being in line with the most relevant literature on regional innovation – are not statistically significant in each set of models. The results are qualitatively the same throughout all the models, with the exception of Model 4 in which *Energy* is not significant anymore and EMAS which presents a stronger association ($p < 0.05$) to process innovation[3].

We also consider a selected sample of firms that have undertook environmental protection expenditures or investment at least one time in the period 2009-2013, based on two variables of the ESEE survey. This restricts the sample to 1666 firms (67% of total firms) in the first-stage. These firms could operate in sectors in which stricter environmental law may force them to sustain some forms of environmental protection cost, or could voluntarily decide to embark in investment in environmental-related equipment. In both cases, these firms may be more sensitive to external green regional commitment; they may react with some EI, and with some additional innovation not strictly environmental. Appendix Table C.1-C.3 show the results with this selected sample (Appendix Table A.3 contains the first-stage estimations).

In general, the main results are replicated, with some slight differences for environmental technologies. In particular, in Appendix Table C.1 *Energy patents* is positive and significant (similarly to the main results in Table 2), while its RTA counterpart is not; in addition, it does not seem that green RTA transportation patents is relevant for this sample selection. Instead, interestingly, *Green patents* as whole exert a positive and significant coefficient ($p < 0.05$). These results suggest that knowledge spillovers for firms that are somewhat engaged in environmental protection are generated by regions more involved in general environmental

[3] For the sake of brevity, these results are not shown, but available upon request.

technologies and – among these – energy technologies (in absolute value, not as specialization) are particularly important.

As far as environmental protection expenditures are concerned (Appendix Table C.2), the statistically significant relation between *EINV* and product innovation is confirmed at a higher level of significance[4], as well as the weakest relation between *EEX* and product innovation (but not in process innovation, as in the main results). For *EMAS* (Appendix Table C.3), we found a more convincing link to product innovation, while the significance on process innovation disappears.

5 Conclusion

This paper aims at investigating whether different dimensions of being a 'green region' could be linked to local firms' innovativeness. Through knowledge spillovers and proximity, firms present in such types of regions could face additional incentives to introduce innovation, besides the traditional firm- and regional-inputs to innovation. Using data on Spanish manufacturing firms and regions, we found that environmental technologies (especially in green energy), environmental expenditures (especially in the form of investments), and environmental management at the level of regions is positively associated with the probability of local firms of introducing innovation.

Our study contributes to the debate on whether the major change at the meso-level is relevant for micro innovation. By drawing on the literature on evolutionary economic geography which stresses the crucial role of change and the interplay between the meso and the micro level in a co-evolutionary perspective (Boschma & Lambooy, 1999; Boschma & Martin, 2007; Iammarino, 2005), we consider the transition toward a greener economy a major shift of technological paradigm or regime (Fankhauser et al., 2013). Hence, we think that there is scarce

[4] Excluding the non-significant controls returns a stronger association ($p < 0.01$).

evidence of how this major change at the meso level affects innovation at the micro, as the regional contributions to EI and overall innovation has received little attention, despite the regional level is considered important (Truffer & Coenen, 2012). In particular, we find that specific environmental characteristics are associated to micro innovation. The characteristics we identified are related to well-established determinants of EI, such as technology (Ghisetti & Quatraro, 2017), regulation (Porter & Van der Linde, 1995) and organizational change (Rennings et al., 2006).

Our study brings relevant policy implications. Many governments and international organizations are increasingly willing to support environmental and social objectives without giving up economic growth. We show that a *greener* region is a fertile ground for the innovative activity of its firms. Since innovation is one of the main determinants of productivity gains and economic growth, our results suggest that policy makers should promote environmental-friendly initiatives by local actors. Going into more details, with regards to green technologies, policies should involve fiscal incentives for firms investing in R&D in the field of energy or transportation (for example, special taxation for income derived from the use of intellectual property), or financing public research centres and universities in environmental fields to allow knowledge spillovers to the business sector. In addition, the results about the indicator on environmental protection expenditures suggest that policy regulation should be less about forcing firms to internalize some cost, and more about making the compliance to the regulation an opportunity to generate value in the future from a current investment. Finally, with regard to environmental management tools such as EMAS, policy makers should encourage local firms to adopt such types of tools, also by considering the obstacles that firms face to adopt EMAS (the lack of resources, the lack of market and stakeholder recognition, and the unclear added value of EMAS).

Our work bears some limitations. In particular, assessing the causality link for the relation between innovation as output and different measures of innovation inputs could be problematic, especially because both firms and regions exhibit some persistence in their innovation capacity (i.e. regions with more innovative firms may tend to have more green patents, environmental production investments and EMAS certifications). We partially control for this by using lagged regressors, but we are aware that this does not eliminate the problem. Hence, we are very careful in interpreting our results as causal link between green regions' characteristics and firms' innovation, but at the same time we believe that our empirical strategy highlights an important – and yet poorly investigated – economic relation.

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Table 1 – Number and percentage of firms introducing innovation

Year	Product Innovation		Process Innovation		Total
	#	%	#	%	
2004	300	21.83	380	27.66	1374
2005	421	22.03	546	28.57	1911
2006	414	20.46	562	27.78	2023
2007	381	18.93	710	35.27	2013
2008	362	18.02	685	34.10	2009
2009	385	19.11	657	32.61	2015
2010	405	20.19	693	34.55	2006
2011	322	17.73	573	31.55	1816
2012	330	17.66	589	31.51	1869
2013	271	16.10	525	31.19	1683

Table 2 -FE panel, regional level: environmental technologies, 2005-2013

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC
Green patents	-0.008	0.000												
	(0.011)	(0.009)												
Energy patents			-0.010	0.007*										
			(0.012)	(0.004)										
Transportation patents					0.042	-0.014								
					(0.026)	(0.027)								
Other Green patents							-0.010	-0.016						
							(0.008)	(0.017)						
RTA Energy patents									-0.235	0.361***				
									(0.334)	(0.089)				
RTA Transport. patents											0.200*	-0.077		
											(0.110)	(0.105)		
RTA Other Green patents													-0.113	0.013
													(0.084)	(0.139)
Business R&D per GDP	-0.292	1.683**	-0.293	1.689**	-0.288	1.684**	-0.274	1.699**	-0.379	1.827**	-0.322	1.697**	-0.267	1.681**
	(0.871)	(0.680)	(0.866)	(0.720)	(0.958)	(0.690)	(0.909)	(0.678)	(0.896)	(0.697)	(0.956)	(0.678)	(0.890)	(0.687)
Public R&D per GDP	-2.007	1.817	-1.873*	1.665	-2.144*	1.844	-2.249*	1.558	-1.761*	1.339	-2.233**	1.881	-2.185*	1.832
	(1.183)	(1.231)	(1.041)	(1.201)	(1.051)	(1.235)	(1.227)	(1.404)	(1.003)	(1.189)	(1.035)	(1.246)	(1.189)	(1.224)
Manufacturing specialization	-0.019	0.077	-0.025	0.088	-0.018	0.079	-0.008	0.080	-0.017	0.087	-0.018	0.080	-0.006	0.076
	(0.093)	(0.051)	(0.091)	(0.053)	(0.084)	(0.051)	(0.091)	(0.053)	(0.089)	(0.053)	(0.086)	(0.051)	(0.092)	(0.052)
Pop. density	0.007	0.006	0.005	0.004	0.004	0.006	0.007	0.012	0.002	0.007	0.002	0.006	0.006	0.005
	(0.014)	(0.015)	(0.014)	(0.016)	(0.016)	(0.016)	(0.013)	(0.017)	(0.014)	(0.016)	(0.015)	(0.015)	(0.013)	(0.015)
Pop. density2	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.472	-3.587*	0.726	-3.638*	0.674	-3.596*	0.273	-4.187*	0.786	-3.774*	1.076	-3.750*	0.251	-3.546*
	(3.113)	(1.810)	(3.267)	(1.925)	(3.457)	(1.938)	(3.226)	(2.209)	(3.353)	(1.972)	(3.356)	(1.818)	(3.246)	(2.005)
# observations	153	153	153	153	153	153	153	153	153	153	153	153	153	153
# groups	17	17	17	17	17	17	17	17	17	17	17	17	17	17
F-test (p-value)	0.00	0.06	0.00	0.02	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.04	0.00	0.03

* p<0.10, ** p<0.05, *** p<0.01.
Robust errors in parentheses.

Table 3 -FE panel, regional level: environmental protection expenditures, 2010-2013

	Model 15 PROD	Model 16 PROC	Model 17 PROD	Model 18 PROC
EEX	-0.901*	-0.845*		
	(0.071)	(0.079)		
EINV			0.734**	0.400
			(0.016)	(0.120)
Business R&D per GDP	-0.323	0.138	0.516	0.827
	(0.849)	(0.921)	(0.769)	(0.624)
Public R&D per GDP	1.879	0.003	1.368	0.563
	(0.314)	(0.999)	(0.526)	(0.765)
Manufacturing specialization	0.078	0.176**	0.043	0.186*
	(0.503)	(0.049)	(0.724)	(0.083)
Pop. density	0.287***	-0.097	0.272***	-0.112
	(0.000)	(0.470)	(0.000)	(0.416)
Pop. density2	-0.000***	0.000	-0.000***	0.000
	(0.000)	(0.583)	(0.000)	(0.444)
Constant	-34.168***	12.202	-34.126***	10.933
	(0.000)	(0.509)	(0.000)	(0.550)
# obs.	68	68	68	68
# groups	17	17	17	17
F-test (p-value)	0.00	0.01	0.00	0.01

* p<0.10, ** p<0.05, *** p<0.01.
Robust errors in parentheses.

Table 4 -FE panel, regional level: environmental management (EMAS), 2005-2013

	Model 19 PROD	Model 20 PROC
EMAS	0.018*	0.020*
	(0.010)	(0.011)
Business R&D per GDP	-0.435	1.512*
	(1.009)	(0.732)
Public R&D per GDP	-2.095*	1.796
	(1.162)	(1.258)
Manufacturing specialization	-0.017	0.068
	(0.095)	(0.052)
Pop. density	0.003	0.006
	(0.015)	(0.014)
Pop. density2	-0.000	-0.000
	(0.000)	(0.000)
Constant	0.824	-3.418*
	(3.504)	(1.800)
# obs.	153	153
# groups	17	17
F-test (p-value)	0.05	0.0

* p<0.10, ** p<0.05, *** p<0.01.
Robust errors in parentheses.

Appendix A

Methodological note

1. **Environmental technologies**

We draw patent applications from the OECD REGPAT database and classify them by the IPC Green Inventory[5] of the World Intellectual Property Organization (WIPO). This classification identifies IPC classes that entail technologies that could significantly improve environmental performance, such as protecting the environment, using resources and treat wastes in a more sustainable way than traditional technologies. In comparison to other classification such as the Indicator of Environmental Technology (ENV-Tech Indicator) by the OECD, WIPO classification has a broader scope (Marin, 2014). We use EPO designated PCT applications that are 'regionalized' by allocating inventor and applicant addresses to each region (Maraut et al., 2008). We take the fractional count of PCT applications aggregated by the region of residence of the inventor, so that when a patent application has multiple inventors resident in different regions, we assign a share to each region (for example, a patent with an inventor resident in Madrid and another resident in Barcelona is equally assign to the Comunidad de Madrid and to Catalonia with a 0.5 share in each). We then select the patents whose IPC codes match the IPC Green Inventory to compute the share of green patents on total patents (*green patents*). We also distinguish green patents by the seven topics of the IPC Green Inventory and group them in three variables (which are calculated as shares on total patents): *energy patents* (i.e. alternative energy production, energy conservation, nuclear power generation), *transportation patents*, and *other green patents* (i.e. waste management, agriculture and forestry, administrative, regulatory, or design aspects). Since for regions with a small number of total patents these shares could overrepresent the importance of green patents, we also

[5] http://www.wipo.int/classifications/ipc/en/est/

calculate a Revealed Technological Advantage (RTA) index of different green-technology groups relative to all patents of the sample:

$$RTA_{rj} = \frac{P_{rj}/\sum_j P_{rj}}{\sum_r P_{rj}/\sum_{rj} P_{rj}}$$

where P_{rj} is the number of patents in region r in group j (j = *energy patents*, *transportation patents*, *other green patents*, *non-green patents*). Thus, this index is defined as a technological field's share of patents in a particular region divided by the technological field's share in all patent fields. It provides, therefore, an indication of the relative specialization of a given region in selected technological domains. To make this index between -1 and +1, we apply the following transformation:

$$adjRTA_{rj} = \frac{RTA_{rj} - 1}{RTA_{rj} + 1}$$

A value of the index close to 1 represents the relative advantage (or specialization) of region r in technology group j. A value close to -1 suggests a disadvantage in a given technology; if the index is equal to -1, the region holds no patent in a given technology. The index is equal to 0 when the region's share in the technological field equals the share of that technology in all patents, suggesting the absence of relative specialization of the region in that technology.

2. Current expenses and investments on environmental protection

The Survey on Industry Expenditure on Environmental Protection carried out by the Spanish national statistics institute (INE) annually since 2008 reports the current expenses and investments on environmental protection made by establishments to avoid, reduce or eliminate the pollution resulting from their activities. The survey provides two main variables: Current expenditures are defined as[6] 'those operating expenses […] whose main objective is the prevention, reduction, treatment or elimination of the pollution or any other degrading of the

[6] See also: http://www.ine.es/en/daco/daco42/ambiente/metoemin_en.pdf

environment arising as a result of the activity of the establishment. It fundamentally comprises the following expenses:

- Payments to other companies for purchases of environmental protection services.
- Payments to the Public Administrations as fees (not including taxes or unrequited payments).
- Expenses associated with the equipment used (repairs, energy consumption and consumption of raw materials).
- Other expenses related to environmental protection, such as personnel employed in environmental protection activities, expenses on R&D activities related to the environment, expenses on personnel training, etc.'

Investments are defined as 'the capital resources acquired to be used in the productive process for more than one year, purchases of capital goods or intangible assets carried out by the company during the reference year.' Examples of investments are: equipment and installations for reducing the emissions of atmospheric pollutants, for the prevention of wastewater, for generating less waste, for saving and reusing water, for reducing the consumption of raw materials and energy.

Table A.1 – Correlation, firm-level analysis

		1	2	3	4	5	6	7	8	9	10	11
1	Size	1										
2	Size 2	0.981	1									
3	In-house R&D intensity	0.152	0.148	1								
4	Permanent R&D	0.397	0.409	0.282	1							
5	Foreign	0.445	0.454	0.039	0.215	1						
6	Export	0.470	0.433	0.160	0.252	0.264	1					
7	Public R&D funding	0.340	0.346	0.363	0.327	0.094	0.227	1				
8	Expansive market	0.114	0.101	0.059	0.048	0.038	0.080	0.076	1			
9	Stable market	0.009	0.009	-0.041	-0.020	0.007	-0.036	-0.045	-0.449	1		
10	Cooperation	0.225	0.245	0.144	0.198	0.099	0.106	0.220	0.047	-0.016	1	
11	High-tech sectors	0.215	0.211	0.255	0.221	0.236	0.223	0.217	0.042	-0.005	0.094	1

* p<0.10, ** p<0.05, *** p<0.01.

Table A.2 – RE logit, firm-level determinants of innovation, 2005-2013

	Product	Process
Size	1.157***	1.079***
	(0.224)	(0.161)
Size 2	-0.057**	-0.059***
	(0.023)	(0.017)
In-house R&D intensity	16.629***	4.339**
	(2.174)	(1.725)
Permanent R&D	0.507***	0.506***
	(0.114)	(0.096)
Foreign	-0.271*	-0.133
	(0.138)	(0.110)
Export	0.860***	0.310***
	(0.126)	(0.087)
Public R&D funding	0.711***	0.528***
	(0.101)	(0.088)
Expansive market	0.123	0.561***
	(0.099)	(0.077)
Stable market	0.001	0.272***
	(0.082)	(0.062)
Cooperation	0.085	0.766***
	(0.172)	(0.157)
High-tech sectors	0.705***	0.148
	(0.132)	(0.098)
Constant	-7.277***	-5.604***
	(0.532)	(0.366)
Panel variance	1.709***	1.125***
	(0.069)	(0.060)
# obs.	16588	16739
Chi 2 (p-value)	0.00	0.00
Log-plh	-5452.88	-8032.54

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.
Explanatory variables are 1-year lagged (except *High-tech sectors*).

Table A.3 – Robustness check: RE logit, firm-level determinants of innovation, selection of firms, 2009-2013

	Product	Process
Size	1.169***	1.032***
	(0.398)	(0.312)
Size 2	-0.072*	-0.044
	(0.040)	(0.032)
in-house R&D intensity	24.826***	3.733
	(3.845)	(2.802)
Permanent R&D	1.065***	0.599***
	(0.213)	(0.183)
Foreign	-0.250	-0.099
	(0.246)	(0.200)
Export	0.972***	0.406**
	(0.260)	(0.186)
Public R&D funding	0.661***	0.718***
	(0.186)	(0.162)
Expansive market	0.168	0.192
	(0.200)	(0.162)
Stable market	0.256*	0.082
	(0.150)	(0.118)
Cooperation	0.286	0.518
	(0.355)	(0.322)
High-tech sectors	0.799***	0.133
	(0.226)	(0.179)
Constant	-8.586***	-6.819***
	(1.545)	(1.227)
Panel variance	1.979***	1.600***
	(0.113)	(0.100)
# obs.	4841	4887
Chi 2 (p-value)	0.00	0.00
Log-plh	-1846.24	-2559.70

* p<0.10, ** p<0.05, *** p<0.01.
Explanatory variables are 1-year lagged (except *High-tech sectors*).

Appendix B

Table B.1 – Correlation, regional analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Business R&D per GDP	1														
2	Public R&D per GDP	0.314	1													
3	Manufacturing specialization	0.552	-0.200	1												
4	Pop. density	0.376	0.421	-0.278	1											
5	Pop. density2	0.365	0.459	-0.255	0.947	1										
6	Green Patents	-0.007	0.172	-0.141	-0.073	-0.081	1									
7	Energy Patents	0.110	0.235	-0.010	-0.113	-0.068	0.818	1								
8	Transportation Patents	0.053	-0.085	0.069	0.024	-0.005	0.065	-0.166	1							
9	Other Green Patents	-0.259	-0.064	-0.340	0.065	-0.026	0.431	-0.063	-0.101	1						
10	RTA Energy patents	0.146	0.229	-0.031	0.007	0.030	0.623	0.814	-0.209	-0.094	1					
11	RTA Transport. patents	0.313	0.144	0.096	0.266	0.210	-0.013	-0.147	0.759	-0.142	-0.057	1				
12	RTA Other Green patents	-0.073	0.116	-0.263	0.199	0.095	0.288	-0.101	-0.131	0.823	0.010	-0.007	1			
13	EEX	0.175	0.169	0.435	-0.374	-0.366	-0.089	0.012	-0.068	-0.228	-0.045	-0.105	-0.092	1		
14	EINV	0.457	-0.009	0.781	-0.396	-0.396	-0.076	0.070	-0.061	-0.314	-0.009	0.003	-0.137	0.633	1	
15	EMAS	0.266	0.252	-0.038	0.448	0.392	-0.132	-0.139	-0.017	-0.016	-0.045	0.194	0.128	0.067	-0.058	1

* p<0.10, ** p<0.05, *** p<0.01.

Appendix C

Table C.1 – Robustness check on a selected sample, FE panel, regional level: environmental technologies, 2005-2013

	Model 1.1	Model 2.1	Model 3.1	Model 4.1	Model 5.1	Model 6.1	Model 7.1	Model 8.1	Model 9.1	Model 10.1	Model 11.1	Model 12.1	Model 13.1	Model 14.1
	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC	PROD	PROC
Green Patents	0.003	0.020***												
	(0.013)	(0.007)												
Energy Patents			-0.004	0.034**										
			(0.010)	(0.015)										
Transportation Patents					0.034	-0.002								
					(0.027)	(0.048)								
Other Green Patents							0.012	-0.008						
							(0.031)	(0.017)						
RTA Energy patents									-0.198	0.875				
									(0.315)	(0.567)				
RTA Transport. patents											0.156	0.023		
											(0.133)	(0.173)		
RTA Other Green patents													-0.215	-0.142
													(0.277)	(0.215)
Business R&D per GDP	1.042	0.598	1.162	0.870	1.194	1.140	0.850	1.344	1.181	0.910	1.303	1.169	1.648	1.488
	(2.324)	(2.412)	(2.201)	(2.394)	(2.204)	(2.322)	(2.566)	(2.454)	(2.188)	(2.305)	(2.278)	(2.334)	(2.417)	(2.442)
Public R&D per GDP	2.865	1.957	2.958	1.251	2.904	1.977	3.126	1.793	3.066	1.106	2.766	1.964	2.224	1.552
	(1.926)	(3.107)	(1.806)	(3.411)	(2.080)	(3.592)	(1.916)	(3.521)	(1.843)	(3.275)	(2.097)	(3.467)	(1.962)	(3.575)
Manufacturing specialization	0.288**	0.371***	0.266**	0.377***	0.296**	0.292**	0.284**	0.287**	0.261**	0.359***	0.299***	0.296**	0.270**	0.289**
	(0.134)	(0.110)	(0.120)	(0.123)	(0.105)	(0.100)	(0.119)	(0.117)	(0.116)	(0.120)	(0.101)	(0.102)	(0.113)	(0.118)
Pop. density	0.105	-0.267***	0.122	-0.347***	0.103	-0.239***	0.118	-0.246***	0.124	-0.306***	0.103	-0.241***	0.088	-0.254***
	(0.141)	(0.043)	(0.149)	(0.091)	(0.142)	(0.061)	(0.135)	(0.074)	(0.146)	(0.066)	(0.142)	(0.059)	(0.171)	(0.078)
Pop. density2	-0.000	0.000***	-0.000	0.000***	-0.000	0.000***	-0.000	0.000**	-0.000	0.000***	-0.000	0.000***	-0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-15.782	27.671***	-17.758	38.153**	-15.924	25.184***	-17.461	26.126**	-18.060	33.552***	-15.879	25.241***	-13.110	27.225**
	(18.781)	(7.303)	(19.510)	(13.643)	(18.958)	(7.803)	(18.041)	(9.661)	(19.241)	(9.156)	(18.964)	(7.591)	(22.699)	(10.393)
# obs.	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00	68.00
# groups	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00
F-test (p-value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* $p<0.10$, ** $p<0.05$, *** $p<0.01$.
Robust errors in parentheses

Table C.2 – Robustness check on a selected sample, FE panel, regional level: environmental protection expenditures, 2010-2013

	Model 15.1 PROD	Model 16.1 PROC	Model 17.1 PROD	Model 18.1 PROC
EEX	-1.057*	-0.676		
	(0.529)	(0.523)		
EINV			0.772*	0.401
			(0.366)	(0.283)
Business R&D per GDP	0.437	0.701	1.390	1.280
	(1.806)	(2.090)	(1.987)	(2.323)
Public R&D per GDP	0.363	0.377	0.084	0.533
	(2.163)	(4.316)	(2.677)	(3.352)
Manufacturing specialization	0.190	0.238**	0.162	0.233*
	(0.130)	(0.106)	(0.152)	(0.121)
Pop. density	0.127	-0.228***	0.109	-0.240***
	(0.157)	(0.060)	(0.150)	(0.053)
Pop. density2	-0.000	0.000**	-0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-12.310	27.668***	-12.664	27.020***
	(21.016)	(8.718)	(20.444)	(7.715)
# obs.	68.00	68.00	68.00	68.00
# groups	17.00	17.00	17.00	17.00
F-test (p-value)	0.00	0.00	0.00	0.00

* p<0.10, ** p<0.05, *** p<0.01.
Robust errors in parentheses.

Table C.3 – Robustness check on a selected sample, FE panel, regional level: environmental management (EMAS), 2005-2013

	Model 19.1	Model 20.2
	PROD	PROC
EMAS	0.025**	0.001
	(0.010)	(0.029)
Business R&D per GDP	-0.243	0.118
	(2.294)	(2.121)
Public R&D per GDP	3.420**	0.274
	(1.510)	(3.559)
Manufacturing specialization	0.247**	0.328**
	(0.109)	(0.128)
Pop. density	0.120	-0.233***
	(0.152)	(0.060)
Pop. density2	-0.000	0.000**
	(0.000)	(0.000)
Constant	-17.888	29.041***
	(21.566)	(9.379)
# obs.	60	60
# groups	15	15
F-test (p-value)	0.00	0.00

* p<0.10, ** p<0.05, *** p<0.01.
Robust errors in parentheses.