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► **To cite this version:**

Danielle Galliano, Simon Nadel, Pierre Triboulet. The geography of environmental innovation: a rural/urban comparison. *Annals of Regional Science*, inPress, 10.1007/s00168-022-01149-3 . hal-03730360

HAL Id: hal-03730360

<https://hal.science/hal-03730360>

Submitted on 24 Jul 2023

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The Geography of Environmental Innovation: A Rural/Urban comparison

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Abstract

This paper aims to contribute to enlarge a geography of eco-innovation. The objective is to study what kind of spatial externalities (specialization, related and unrelated variety) has the most positive impact on eco-innovation, according to firm's location (rural, peri-urban, urban). We empirically test this framework using a hurdle negative binomial model on firm-level data drawn from the French Community Innovation Survey (CIS for 2014). The results show that spatial externalities have different effects depending on the firm's engagement and breadth of eco-innovation as well as on its location. Marshallian specialization has a positive effect both on engagement and breadth of eco-innovations unlike unrelated variety, which negatively impacts breadth of eco-innovation. As regard to the firm's location, related variety is particularly correlated to the eco-innovation breadth of rural firms, whereas specialization is positively correlated to the breadth of eco-innovations of peri-urban firms. As for urban firms, spatial externalities seem to have less impact on their eco-innovation related behavior.

Keywords

Eco-innovation; spatial externalities; related variety; rural; French industry

JEL

Q55; O33; L60; R3

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1. Introduction

In a context of climate change that requires that the impacts of production activities be reduced, the question of the foundations of environmental innovation is receiving increasing attention in the economic literature (Barbieri et al. 2016). Environmental innovations (or eco-innovations) refer to a wide range of economic activities, and can be defined as new or improved processes, equipment, products, techniques, or management systems that avoid or reduce the environmental impact of activities (Arundel et al. 2007; Horbach 2008). The literature has extensively explored the question of the determinants of eco-innovation, placing emphasis not just on environmental regulations (Porter, 1991; Porter and van der Linde, 1995), but also on the importance of "technology push" and "market pull" factors in firms' adoption of those innovations (Horbach et al. 2012; Rennings 2000). However, the literature on environmental innovation has shown little interest in the spatial dimension, even though research in the geography of innovation and on regional innovation systems has largely demonstrated the importance of spatial factors in innovation processes (Asheim et al. 2007; Audretsch and Feldman 2004; Boschma 2015). A few recent studies have highlighted this territorial dimension as playing a particularly important role in eco-innovation (Hansen and Cohen 2015, Coenen et al. 2012; D'Agostino and Moreno 2019, Horbach and Rammer 2018), and have focused on the specific role of green start-ups (Colombelli and Quatraro, 2019; Corradini, 2019; Giudici et al. 2019; Sunny and Shu 2019; van den Berge et al., 2020). Thus, in their review of the literature on the geography of transitions, Hansen and Cohen (2015) underline the importance of the specificities of territories - particularly their endowment with natural resources, public policies, and local markets - and highlight the key role of local industrial specialization in ensuring a sustainable transition. Therefore, the recognition of the

role of local conditions in innovation dynamics prompts us to look at the diversity of areas, whether urban or rural; due to their low density, rural areas have often been seen as low innovative areas and are consequently seldom studied in the literature. Rural areas represent more than half of the French national metropolitan territory (53.9%) but only 17.2% of the population and 14.9 % of total employment. By contrast, the manufacturing sector is over-represented in these rural areas, which account for 22% of the total manufacturing employment. Thus, even though rural areas are often considered to be at a disadvantage due to their low degree of attractiveness and innovation, they offer an important industrial base that goes well beyond the primary industries traditionally present in these areas. A better understanding of eco-innovation dynamics in rural areas (as a complement to what exists in urban areas) appears today to be a critical issue for European policies, and this study seeks to shed light on these dynamics, using the case of French manufacturing firms.

In this context, the challenge is to shift towards a territorial approach to eco-innovation by characterizing and testing the spatial factors of eco-innovation. Thus, our study aims to build a theoretical and methodological framework for analyzing the role of spatial externalities in the eco-innovative performance of manufacturing firms, by taking into account their location (urban/rural/peri-urban). This makes it possible to examine which types of externalities - economies of location/ urbanization economies / related variety - are the most conducive to the development of environmental innovations according to firm's location.

Our contribution is both theoretical and empirical. Drawing from both the literature on environmental innovation and evolutionary economic geography, our theoretical approach enables us to take into account the interactions between firm's internal organization and external environment. The objective is to analyze the role of the different types of spatial externalities in the eco-innovative performance of firms and therefore to contribute to the

extending of a geography of eco-innovation. The originality of this study lies in our microeconomic approach to this geography, based on firm-level data; this enables us to characterize spatial externalities (at the plant level) as well as to study firms' engagement in eco-innovation and the breadth of their eco-innovation portfolio (Community Innovation Survey 2014), while taking into account the location of the firm. One could notice that the rare works using such approach distinguishing engagement and breadth in the firm's eco-innovation process (cf especially Ghisetti et al. 2015, Galliano and Nadel, 2015) did not taken into account the influence of spatial externalities and firm location. Furthermore, we propose an analysis of the eco-innovative behaviour of all industrial firms and not only those involved in the cleantech field.

This analysis will help to take into account the spatial dimension, and in doing so, to contribute to the debate on the respective impacts of the different types of externalities on eco-innovation.

Our empirical contribution lies in proposing a territorial firm-level approach to eco-innovation that considers both the location of firms (urban, rural, and peri-urban) and the nature of the spatial externalities present in their spatial environment. These externalities (specialization, related, and unrelated variety) are measured based on the number of employees in manufacturing units in 2014, at the level of employment areas. Thus, each firm is associated with a specific type of spatial environment and presents a profile of externalities corresponding to the characteristics of its employment area. The data on firms' innovation is drawn from the Community Innovation Survey (CIS 2014), representative of all French industrial sectors. For each firm, we create an eco-innovation score measuring the firms' eco-innovation breadth. The econometric model used to analyze the determinants of eco-innovation is a hurdle model. This model helps to distinguish the factors that motivate

manufacturing firms into engaging in an environmental innovation process from those that explain their eco-innovation breadth. In addition to a general model for the whole French industry, we have developed three models for urban, peri-urban and rural firms to provide a more in-depth analysis of this geography of eco-innovation.

The article is organized into 4 sections. In the following section (2), we present our theoretical framework by raising the question of the influence of spatial externalities on firms' eco-innovative performance, with reference to the specialization / related and unrelated diversity debate. We then present the data and the econometric model used to assess the impact of these different types of externalities on eco-innovation (3). Section 4 presents the results for four models, a general model and three sub-models (urban, peri-urban and rural) according to the different types of firm location. The last section summarizes and discusses the main conclusions and implications in terms of public policies.

2. Theoretical framework and hypotheses: spatial determinants of eco-innovation

In line with Porter hypothesis (Porter 1991; Porter and van der Linde 1995), the literature in environmental economics has largely focused on analyzing the effects of regulation and cost considerations on the adoption of environmental innovations. While recent studies share the view that these determinants are even more important for eco-innovations than they are for non-environmental innovations (De Marchi 2012; Horbach et al 2012), they also do show the limitations of an approach that over-focuses on the impact of regulation without taking into account the diversity in firms' behaviors (del Rio Gonzalez 2009; Pereira and Vence 2012), and especially in how they mobilize both material and immaterial resources in the eco-innovation process (Galliano et al. 2019; Horbach et al. 2012). Thus, one of the challenges

lies in analyzing the interactions between the microeconomic characteristics of firms and the characteristics of their environment, beyond regulation alone.

To innovate, a firm must combine its internal knowledge base with external information and knowledge. This dimension is particularly crucial for eco-innovations that require more external sources of knowledge and information (Horbach et al 2013) and more knowledge inputs from heterogeneous sources than other types of innovations do (Ghisetti et al 2015). Thus, some geographic environments are recognized as fostering innovation while others are considered less conducive to innovation processes (Shearmur 2012). The notion of agglomeration is central to the analysis of spatial externalities. It often leads to reducing the benefits of a location to the advantage of being located in a densely populated area, without taking into account the diversity of territories and the different forms of externalities that can occur depending on the type of environment firms are located in (Galliano et al. 2015; Torre and Wallet 2014). Thus, while it is generally accepted that there is a positive correlation between agglomeration and activity diversity, it seems important, as Frenken et al. (2007) have emphasized, to distinguish - both theoretically and methodologically - agglomeration - related phenomena from questions of activity diversity when analyzing firms' innovative and eco-innovative performances. What types of externalities have the most positive impact on eco-innovation performance? and how does the degree of agglomeration influence the interaction between firms and their spatial environment in eco-innovative processes?

The following section aims to present the framework for analyzing the microeconomic determinants of environmental innovation, while taking into account the nature of spatial externalities (2.1) and the firms' characteristics, which condition their ability to capture knowledge externalities and local resources (2.2).

2.1 Spatial externalities and eco-innovation

Following the seminal works of Marshall (1890) and Jacobs (1969), the economic literature on the spatial determinants of innovation has largely emphasized the role of spatial externalities in firms' innovative performance (Boschma 2015; Feldman and Kogler 2010; Neffke et al. 2011), and has highlighted three types of externalities: specialization, unrelated and related varieties. However, these studies diverge as to which forms of externalities are conducive to innovation (Beaudry and Schiffauerova 2009; Galliano et al. 2015; Neffke et al. 2011) and the same questions are debated in the emerging literature on eco-innovation (Barbieri et al. 2020; Santoalha and Boschma 2021; Pei et al. 2021).

As regards specialization externalities, such as described by Marshall (1890), they are likely to foster the development of networks of specialized suppliers; specialization facilitates access to a dedicated workforce and the diffusion of knowledge among firms operating in the same sector. The literature on eco-innovation has paid little specific attention to the role of Marshall externalities, with the exception of studies on the Emilia-Romagna's industrial district, which have highlighted that being located in an industrial district has a positive effect on eco-innovation (Antonioli et al. 2016; Cainelli et al. 2011, 2012; Mazzanti and Zoboli 2008), the idea being that spatial proximity, the effects of inter-sectoral complementarities and the sharing of a common institutional and social environment within the district promote eco-innovation. Recent research in the fields of transition studies and evolutionary economic geography also provides some empirical evidence of this effect. In their literature review, Hansen and Coenen (2015) highlight that industrial specialization has been observed to be a condition for the development of the innovations necessary for sustainability transitions, and that intra-industrial knowledge spillovers enhance firms' capacity to develop eco-innovations. One of the main arguments proposed by studies on local technological and

industrial specialization is that geographic clustering promotes the development of the innovations that are necessary for a transition towards sustainability (Bridge et al. 2013; McCauley and Stephens 2012). It promotes knowledge spillovers and cleaner technology among various firms in the same sectors and may improve resource utilization efficiency within the industry (Pei et al. 2021) and lead to more efficient centralized pollution control (Shao et al, 2019). This effect is reinforced by the fact that regional policies often aim to promote a cluster's key innovative activities in priority, thus reinforcing existing specializations (see Corsatea 2016, in the Italian case of renewable energy technologies). Moreover, the environmental dimension increases uncertainty in the decision to eco-innovate (DiMaggio and Powell, 1983). Specialization effects, which, by definition, are intra-sectoral, are related to the coercive dimension of environmental regulations and to mimetic mechanisms, both of which promote the adoption of green practices within the same sector. Moreover, specialization implies a normative isomorphism based on specific sectoral mechanisms (professional journals and associations, etc.) or more broadly the adoption of codes of good environmental practices (Berrone et al. 2017; Galliano and Nadel 2015; Boutry and Nadel 2021).

Hypothesis 1: Specialization promotes engagement and positively influences the breadth of firms' eco-innovations.

By contrast, and according to Jacobs' (1969) work, agglomeration generates externalities that foster innovation when a territory houses a variety of industries, as this facilitates the sharing and recombination of diverse knowledge and the emergence of new ideas, this diversity being particularly crucial for eco-innovation (Ghisetti et al. 2015; Barbieri et al. 2020). Research on the effects of unrelated variety on eco-innovation is scarce, not unanimous on the subject and do not clearly distinguish engagement and breadth of the eco-innovative process. Barbieri et

al. (2020) highlight that diversification effects differ according to the degree of maturity of the green technology. They show that the more diverse the spectrum of know-how and technological domains is in a region, the greater the potential of green technology development. For Santoalha and Boschma (2021), “the transition literature has a tendency to suggest that unrelated diversification would be more common in processes of sustainable transition”, by focusing on the role of niches and actors with distant knowledge bases as the mainstay of socio-technical transition (Geels and Raven 2006; Hansen and Coenen 2015).

Yet, scholars in evolutionary economic geography point out that related diversification is the rule and unrelated diversification the exception (Hidalgo et al. 2018; Pinheiro et al. 2021); and scholars that apply a relatedness framework find that new green activities that are more likely to be developed in a region in which activities related to such green activities already exist (Tanner 2014; Van den Berge et al. 2020; Montresor and Quatraro 2019). In this emergent and discordant literature, studies are often based on patent data, and do not distinguish rural and urban areas. Overall, unrelated variety could have a positive influence on a firm’s engagement in innovation processes (see technological opportunities, Malerba 2010) and, beyond rare cases, a less positive effect on the breadth of the firm’s eco-innovation. This effect can even be negative when competition for resources increases and there is little exchange of information between sectors (Pei et al 2021). This is particularly important for rural areas that are characterized by “slow innovators” and more incremental forms of innovation (Shearmur and Doloreux 2016; Naldi et al. 2015). These first indications from the literature provide elements in order to formulate the hypotheses and the empirical results will allow to provide empirical evidence to support them.

Hypothesis 2: Unrelated variety positively influences engagement in an eco-innovation process but does not have a positive effect on the breadth of eco-innovations

Finally, recent developments in the geography of innovation have highlighted different forms of variety and distinguished related from unrelated varieties (Frenken et al. 2007). The combined contributions of evolutionary economic geography and transition studies have recently emphasized the importance of the effects of inter-sectoral complementarities in a territory, through the exchange of diverse but related knowledge (Boschma 2015; Boschma et al. 2017; Hansen and Coenen 2015; Neffke et al. 2011). Various studies have made strong arguments about the importance of the local dimension in the transition to sustainability. Indeed, they find that new green activities are more likely to develop in regions where related activities already exist, and in regions that already have strong skills and knowledge bases in a particular sector (Montresor and Quatraro 2019; Santoalha and Boschma 2021). These studies use approaches based on "smart specialization" which involves exploiting existing local capabilities and using them towards diversification into related activities (Balland et al. 2019; McCann and Ortega-Argiles 2015).

This translates into a "branching process" with the development of new activities rooted in related activities that are already present in the territory (Frenken and Boschma 2007). These dimensions are particularly important for environmental innovations, beyond patents and disruptive innovations. The branching process allows for the mobilization of non-technological resources and knowledge, which play a major role in firms' eco-innovation behavior (Asheim et al. 2007). Montresor and Quatraro (2019) have shown that relatedness to preexisting local knowledge, whether green or non-green, had a positive effect on the development of green innovation technologies in European regions. General purpose and key enabling technologies play a similar role in green innovation (cf. Montresor and Quatraro 2019). Moreover, at the firm level, inter-organizational relationships are often central in the implementation of the process of transition towards sustainability, particularly in eco-

innovative collaborative projects that arise from co-location (Hansen and Coenen 2015; McCauley and Stephens 2012). In this context, studies on the circular economy or territorial industrial ecology are a rich source of insight into how co-located actors with different but related activities collaborate towards eco-innovation (Gallaud and Laperche 2016; Galliano et al. 2019). The case of collective methanisation projects, founded on the mobilization of local resources and biomass, illustrates the dynamic of circular economy projects whose first goal is to bring together actors with different activities to reinforce the use of new technologies and facilitate the connection between previously unrelated actors (Castaldi et al. 2015; Geels and Raven 2006). The effectiveness of this type of externality is also related to the complementary nature of the knowledge exchanged, particularly between the old and new activities present on the territory (Iammarino 2011; Munro and Bathelt 2014). Overall, these different studies tend to highlight and confirm that local factors and the historical economic trajectory of the territories (path dependencies) shape the firms' eco-innovation strategies.

Hypothesis 3: Related variety has a positive influence on firms' engagement in eco-innovation and on the breadth of these eco-innovations.

2.2 Firms' characteristics: location, internal structures, and market and regulatory environments

The literature shows that a firm's innovation behavior depends on both its internal characteristics and external environment and notably its location (Malerba, 2010). First, we make a distinction between urban, peri-urban, and rural locations. The aim here is to examine the link between the degree of agglomeration and spatial externalities. Secondly, we present the main factors identified in the literature relating to the firm's internal structure and its market, sectoral, and regulatory environment.

2.2.1 The impact of externalities and agglomeration on eco-innovation: location in an urban, peri-urban, or rural area

The notion of agglomeration economy relates to the idea that spatial proximity - i.e., being located near other agents - contributes positively to firms' innovative performance. However, firms' potential for interaction varies according to the degree of agglomeration (density) of their location area. Indeed, a high degree of density is generally associated with a larger diversity of activities, and is therefore, in principle, more conducive to so-called Jacobian externalities. However, it seems important to distinguish, from a conceptual point of view, between the notions of agglomeration and externalities in the analysis of firms' innovative and eco-innovative performance. Indeed, by emphasizing the notion of agglomeration, the literature has implicitly considered that low density is synonymous with low innovation intensity, when, in fact, firms in rural areas are also innovative (Shearmur and Doloreux 2016) and have capacities to access a variety of resources for innovating. These include local natural resources¹, which play a particularly important role in eco-innovation (Esparcia 2014; Galliano et al. 2019) and sustainable transitions (Hansen and Coenen 2015) but also strong capacities to collaborate and mobilize their networks (Grillitsch and Nilsson 2015; Esparcia 2014).

The literature generally distinguishes three types of areas - urban, peri-urban and rural - according to their degree of density, which determines the intensity of agglomeration economies, and in particular the size of the infrastructure network and public facilities, the consumer pool and the labor market, and the concentration of tertiary activities.

¹ For example, the potential of tidal power generation in coastal regions; or the potential of solar energy in regions with high sun exposure, the weight of soya crops on biodiesel (Hansen and Coenen 2015; Carvalho et al. 2012).

As regards **urban areas**, they have specific characteristics that benefit firms - namely a higher concentration of public goods and transport infrastructures - and they allow access to a dense and diversified human capital, which facilitates the flow of information and knowledge (Glaeser et al. 2010). But urbanization also produces negative externalities related to the effects of urban congestion and land cost, which can influence firms' environmental behavior and choice of location for their activities (e.g., co-location of headquarters, relocation of productive activities, etc.). In dense urban areas, a wide variety of industrial and tertiary activities generally coexist alongside more specialized clusters, all of which are sources of diversified knowledge spillovers. This density of diverse and sometimes related activities proves to be an asset in transforming activities towards more sustainability, by stimulating synergies between different technological domains and between different networks of actors (Coenen et al. 2012). This collocation of firms in the same area is conducive to related and unrelated varieties, which should positively influence firms into engaging in eco-innovation, as per our second hypothesis.

As for **rural areas**, their low density is associated with lower diversity and availability of skills and resources and a lesser presence of industrial and tertiary activities, although local specialized clusters can also exist in those areas. Low density also implies less industrial diversity, less local interactions, and therefore fewer knowledge spillovers. Nevertheless, among these low density areas, there are path-dependent eco-innovation opportunities with an innovative pathway framed by the existing industries and the subsequent positive effects of related variety externalities. Thus, the literature tends to highlight that related variety helps to compensate for low density (Camagni and Capello 2013; Galliano et al. 2019; McCann and Ortega-Argiles 2015; Naldi et al. 2015). This is particularly relevant for the development of eco-innovative activities, which is often based on the mobilization of place-based resources and on a combination of old and new activities on the territory (Iammarino 2011; Munro and

Bathelt 2014). Thus, it is thought that there is a dynamic whereby previously unrelated actors and technologies come into relation with one another (Castaldi et al. 2015). This dynamic is made possible by the strong capacity of rural firms to collaborate in order to obtain the resources they do not have (Grillitsch and Nilsson 2015).

Finally, it would seem that even if Marshallian effects (mimetic, proximity, or intra-sectoral competition), or unrelated diversification effects may play a role in the engagement of rural firms, studies tend to show that related variety plays a major role in the breadth of eco-innovation, which is in line with our hypothesis 3.

Peri-urban areas – which have been little studied to date - are the interface between urban and rural territories. They, by definition, strongly interact with cities but tend to have a more residential function and present fewer of the negative externalities associated with urban density (such as land costs and congestion problems), while benefiting from proximity to consumers and urban infrastructure. As recent studies have shown, these areas are also undergoing profound changes and follow highly diverse trajectories (Nessi et al. 2016). Even if the current dynamics show increasing tendencies towards the creation of their own endogenous dynamics (Nessi et al. 2016), peri-urban areas are strongly interconnected to urban centers through employee mobility, but also urban knowledge spillovers derived from human activities. They are often home to production and logistics activities, which can influence their eco-innovative behavior.

2.2.2. Firms' internal and external characteristics

Beyond firms' location, the literature on eco-innovation has identified several determinants of environmental innovation, related to firms' structural characteristics and those of their environment (sectoral, market, and regulatory) (Cuerva et al. 2014; Horbach 2008; Horbach et

al. 2012, 2013). These variables are taken into account in our analysis and serve as control variables.

Regarding the structural characteristics of firms, numerous studies show that their capacity to eco-innovate fundamentally depends on their internal resources - which vary according to their size, to whether or not they belong to a group, and to their R&D activities (Galliano and Nadel 2015; Horbach et al. 2012 2013). Environmental innovation, which is fundamentally complementary to technical and organizational innovation, is correlated with the firm's technological intensity and to processes of change in its internal and external organization (Antonioli et al. 2013; Horbach et al. 2012).

Beyond spatial externalities, eco-innovation depends on more traditional knowledge externalities related to firms' market, regulatory and sectoral environment (Rennings 2000). Eco-innovative processes are subject to different forms of environmental policies (Porter and van der Linde 1995; Rennings 2000). Empirical studies on environmental innovation highlight the strong effect of existing and anticipated environmental regulations (Barbieri et al. 2016; Cainelli et al. 2020). Similarly, the demand generated by a competitive market such as those in which exporting firms operate is also a factor that promotes eco-innovation (Horbach, 2008).

These regulatory and market pressures, which incite firms to engage in eco-innovation, strongly vary from sector to sector. The sector, via the appropriability conditions of innovation and the technological opportunities it provides, plays a key role in the dynamics of adoption and the intensity of eco-innovation (Galliano and Nadel 2015). Thus, a firm's need to maintain or improve its reputation, as well as the introduction of sectoral codes of good practices, are, according to the literature, decisive factors in its engagement in environmental innovation and in its intensity (Berrone et al. 2017; Galliano and Nadel 2015).

3. Data and Methods

We used data from two mandatory public surveys conducted by the French National Institute of Statistics (INSEE)². CIS 2014 is a survey that aimed to assess the innovation performance of firms – including their eco-innovation performance - over a three-year period, from 2012 to 2014. 4,541 manufacturing firms - representative of the 26,666 French manufacturing firms with more than 10 employees – were surveyed. The DADS 2014 census (Annual Declarations of Social Data) provides information on employment for all establishments in the manufacturing sector. The 96,465 plants with at least one employee serve as the basis for calculating the specialization and diversification indices for each employment zone used for characterizing the spatial profile of firms in our sample.

3.1 Spatial externalities and location

3.1.1 Measuring Externalities

Different indicators make it possible to characterize the sectoral specialization/diversification of geographical areas. We have selected three indicators that are widely used in the literature to assess spatial externalities: Location Quotient (LQ), Unrelated Variety (UV), and Related Variety (RV). The first is traditionally used to measure Marshallian externalities (Beaudry and Schiffauerova 2009) while the other two measure unrelated versus related diversification (Frenken et al. 2007). We use the 304 metropolitan employment areas for the geographical disaggregation and two nested sectoral levels for the sectoral disaggregation. LQ and UV are

² We have access to confidential individual data for these two surveys following a statistical confidentiality agreement. See <https://www.casd.eu/en/>. This allows us to have access to all the information, and in particular the accurate location (at the municipality level) of plants and head offices of firms.

measured by dividing industry into 12 manufacturing sectors³. Related diversity is measured using the finest (5-digit) level of the French classification of activities (NAF rev. 2), which has the same structure as the European classification NACE rev.2. All measurements are based on the number of employees in the 96465 establishments from DADS for 2014.

p_k is the share of employees in sector k in the total manufacturing employment.

$p_{k,i}$ is the share of employees in sector k in the manufacturing employment of zone i .

The LQ compares the weight of sector k in zone i to the weight of the same sector in the total employment. On this basis, we observe that an LQ greater than 1 indicates relative sector specialization and that the closer to 0 the LQ is, the more under-represented sector k will be in zone i .

$$LQ_{k,i} = \frac{p_{k,i}}{p_k}$$

The UV and RV, calculated for a zone, are the two components of a global entropy measure that can be decomposed between an entropy between sectors (UV) and within sectors (RV) (Frenken et al., 2007). The UV makes it possible to assess the employment distribution across the various sectors present in the zone. If only one sector is present in zone i , the UV is zero. The maximum value in a zone is reached when employees are equally distributed among all sectors present in the zone. This maximum value depends on the number of sectors present in the zone.

$$UV_i = \sum_{S_k \in Z_i} [p_{k,i} \times \log_2(p_{k,i}^{-1})]$$

$S_k \in Z_i$ means that only the sectors represented in zone Z_i are considered.

³ We use the level A38 of the French Aggregated Nomenclature (2008 NA), which divides the manufacturing sector into 12 large categories of activities (see Table A1 in Appendix). Level A38 is an international intermediate level between sections and divisions that is suitable for the purpose of characterizing a breakdown into manufacturing sectors.

The RV calculated for a zone makes it possible to take into account the diversity of activities within each sector. Each sector is sub-divided into basic 5 digit-level activities and a first calculation helps to determine - using the same formula as for the UV - the degree of diversification of basic activities within a sector. The RV is the weighted average of the degrees of diversification of all the sectors present in the zone. The RV is equal to 0 if only one activity of only one sector is present in the zone. The maximum value will depend on the number of sectors present in the zone, on the number of activities present in each sector, and on the distribution of labor among the activities of a sector. Theoretically, this maximum value will be reached when the workforce is distributed homogeneously among the different activities of the sector with the greatest number of activities.

$$RV_i = \sum_{S_k \in Z_i} [p_{k,i} \times H_{k,i}]$$

$$\text{with } H_{k,i} = \sum_{A_j \in S_k * Z_i} [p_{j,k,i} \times \log_2(p_{j,k,i}^{-1})]$$

$A_j \in S_k * Z_i$ means that only five-digit activities belonging to sector S_k and represented in zone Z_i are considered. $H_{k,i}$ is a measure of entropy similar to UV_i . Within a zone i , $H_{k,i}$ measures entropy at the level of the basic activities within a sector, while UV_i measures entropy at the level of the sectors. Due to the decomposable nature of the entropy, the entropy measured at five-digit levels is equal to the sector-level entropy (UV_i) and the weighted sum of five-digit entropy within each sector ($RV_i = \text{sum}(H_{k,i})$).

In our model, each firm benefits from a spatial environment (SE) corresponding to the employment zone i in which it is located (UV_i and RV_i), taking into account its sector of activity for the specialization indicator ($QL_{k,i}$).

3.1.2 Location of the firm

To determine what type of zone firms are located in, we use the "Zoning into Urban Areas", defined by the National Institute of Economic Statistics (INSEE, ZAU 2010). Urban centers are urban units with 10,000 employees or more; peri-urban areas are defined as municipalities in which over 40% of the residents commute to urban centers for work. Thus, urban centers refer to a high density of population and employment, while peri-urban areas refer to a high level of commuting to urban-based jobs. The rest of the territory is made up of semi-urban centers with small towns located in their periphery, outside urban centers' sphere of influence. In this paper we consider these areas as rural areas, taking into account their low population and employment densities (Table A2 in Appendix).

3.2 Control variables from CIS

To characterize firms and their environment, we have used three types of control variables drawn from the innovation survey as described in section 2.2.2.

For firm's internal characteristics, the size of the firm and its belonging to a group are taken into account as well as its engagement in the different forms of innovation (product, process and organizational). Finally, the presence of a permanent internal R&D team is an indicator of the firm's capacity to develop innovations, including eco-innovations⁴.

To control for sectoral and market conditions, we use the activity level A17 of NA2008 (INSEE), which divides the manufacturing industry into 4 classes, and the main market of the firm, which can be local (corresponding to the French NUTS2 level), national or international.

The rate of adoption of eco-innovation by employment area is used as a proxy for mimetic

⁴ Many of the questions on innovation capacities are addressed only for innovative firms in the French CIS. This limits the construction of control variables on the whole population. Consequently, we retained the permanent presence of an internal R&D team, with the assumption that non-innovative firms over a 3-year period did not have this resource.

effects and normative pressure that can push firms to eco-innovate and increase the scope of these eco-innovations.

Finally, motivations for eco-innovation are used as a set of factors that can influence eco-innovative firms into extending the breadth of their eco-innovations.

Table 1 shows the statistics of the variables for the whole population and for the sub-populations of urban, peri-urban and rural firms (see Table A3 for the definition of the variables in the appendix). Between 2012 and 2014, approximately 62% of the total firm population implemented innovations, in the broad sense (product, process, marketing, or organizational), and 35% eco-innovated.

Table 1: Descriptive statistics of the variables

Variables	Total		Urban		Peri-urban		Rural	
	firms	eco-firms	firms	eco-firms	firms	eco-firms	firms	eco-firms
<i>Location and spatial externalities</i>								
Innovation in %	61.8	100	63.1	100	60.6	100	60.2	100
Eco-innovation in %	34.7	100	36.8	100	33.6	100	31.4	100
Specialization	1.37 (1.13)	1.47 (1.30)	1.35 (1.12)	1.42 (1.22)	1.29 (1.06)	1.40 (1.34)	1.52 (1.22)	1.68 (1.45)
Related Variety	2.28 (0.48)	2.28 (0.48)	2.36 (0.46)	2.35 (0.46)	2.31 (0.45)	2.31 (0.46)	2.09 (0.51)	2.07 (0.51)
Unrelated Variety	2.94 (0.39)	2.95 (0.39)	3.00 (0.40)	3.00 (0.41)	2.97 (0.34)	2.97 (0.33)	2.79 (0.37)	2.78 (0.37)
<i>Firm's internal characteristics in %</i>								
Group	42.8	52.5	46.9	55.4	39.7	49.4	37.8	48.8
Product innovation	33.6	63.9	35.2	65.0	32.6	64.4	31.2	60.4
Process innovation	33.7	63.2	33.8	61.2	33.2	64.2	33.9	67.1
Organizational innovation	36.1	64.9	36.7	64.4	36.8	65.2	34.1	65.7
Permanent R&D	21.2	43.2	23.3	46.4	20.6	42.5	17.3	36.2
Firm size :								
10-19	40.1	28.2	38.3	28.0	42.9	29.0	40.9	27.7
20-49	34.0	31.3	34.3	29.7	33.7	32.2	33.8	34.4
50-249	20.5	29.4	20.3	28.2	20.2	32.2	21.1	29.1
More than 250	5.4	11.1	7.0	14.1	3.1	6.6	4.3	8.9
<i>Firm's market and sectoral environment in %</i>								
Sector :								
Agri-food industry	13.3	14.5	10.3	10.7	14.6	17.8	18.3	20.2
Equipment goods	13.1	17.3	14.8	20.5	12.9	14.9	9.8	12.1
Transport	3.8	4.1	3.8	4.8	4.1	2.7	3.6	4.0
Others industrial products	69.7	64.1	71.1	64.0	68.4	64.5	68.4	63.7

Main market :	Local	40.4	28.8	41.6	28.8	39.7	27.8	38.7	29.9
	National	46.3	51.6	42.8	48.1	48.8	55.6	51.3	55.7
	International	13.2	19.6	15.7	23.1	11.5	16.6	10.0	14.4
Adoption rate of eco-innovation in the area		44.3 (14.8)	44.8 (15.2)	45.9 (13.2)	46.1 (13.3)	44.8 (13.1)	43.6 (13.3)	40.5 (18.4)	42.8 (20.4)
Motivations of eco-innovation in %									
	Existing regulations		67.2		69.0		63.1		67.5
	Existing taxes		44.27		41.9		43.1		51.5
	Regulations or taxes expected		50.4		51.1		47.5		51.9
	Subsidies		28.6		27.2		28.2		32.3
	Current or expected demand		44.7		47.2		44.5		39.1
	Reputation		70.0		70.1		69.1		71.1
	Voluntary actions for good practice		64.5		65.4		63.1		63.7
	Cost : energy, water, materials		64.7		61.7		66.5		69.7
	N° observations	4 541	2 052	2 445	1 202	1 051	437	1 045	413
	weighted	26 666	9 248	13 425	4 944	6 807	2 287	6 434	2 018

Sources: CIS 2014 & DADS 2014. All variables are dummies, with the exception of externalities' indicators (specialization, related and unrelated variety) and adoption rate of eco-innovation in the area. Standard deviations are shown in brackets for these 4 variables.

3.3 Models and dependent variable

Environmental economics has for the most part focused on testing the effects of environmental policy instruments using indicators of patents or R&D spending (Jaffe and Palmer 1997; Popp 2006). Innovation economics, on the other hand, has more concentrated its attention on innovation processes, and notably the decision to engage or not in a process of eco-innovation (Galliano and Nadel, 2018, Horbach 2008, Horbach et al. 2012), using CIS data. Beyond the engagement process, we also aim to analyze the breadth of eco-innovations, defined as the portfolio of the various innovative environmental practices implemented by the firm. Firms' breadth of eco-innovations has seldom been considered in studies on environmental innovation (Galliano and Nadel, 2015, Ghisetti et al. 2015).

3.3.1 The dependent variable: the eco-innovation score

To measure breadth, we construct a score of eco-innovation based on the 14 environmental innovation modalities identified in the CIS 2014 survey. These modalities refer to

environmental benefits that occur either during the production process (8 modalities) or during the consumption of the product by the end-user (6 modalities) (see table 2).

[Table 2: Eco-innovation according to firm’s location]

Types of environmental innovation	in % of firms	Total firms	Urban firms	Peri-urban firms	Rural firms
<i>Environmental benefits obtained during the production process</i>					
Reduction of material use per unit of output		21.3	24.0	17.4	19.0
Reduction of water use per unit of output		14.1	16.2	12.9	10.3
Reduction of energy use per unit of output		23.2	25.7	20.4	20.4
Reduction of CO ₂ emissions per unit of output		13.8	16.4	10.7	10.6
Reduction of air, water, noise or soil pollution		16.3	18.7	13.5	13.6
Replacement of a share of materials with less polluting or hazardous substitutes		21.2	25.0	17.1	16.4
Replacement of a share of fossil energy with renewable energy sources		4.5	5.1	3.5	4.2
Recycling waste, water, or materials for own use or sale		24.9	27.1	23.2	21.7
<i>Environmental benefits obtained during the consumption process</i>					
Reduction of material use per unit of output		14.7	18.5	11.9	8.9
Reduction of CO ₂ emissions per unit of output		10.3	12.9	8.4	5.9
Reduction of air, water, noise or soil pollution		9.1	11.4	7.2	5.7
Facilitation of recycling of product after use		12.7	14.4	11.6	10.1
Extended product life through longer-lasting, more durable products		10.9	13.2	8.7	7.6
Reduction in the amount of packaging waste		11.1	11.5	10.5	10.6

Source : CIS 2014

The score variable Y_i will enable us to analyze the microeconomic foundations of eco-innovation breadth. We postulate that the higher the score, the higher the breadth of environmental innovation.

- $Y_i = 1$ if the firm’s innovations only produce one environmental benefit
- $Y_i = 2$ if the firm’s innovations produce two environmental benefits
- ...
- $Y_i = 14$ if the firm’s innovations produce all environmental benefits

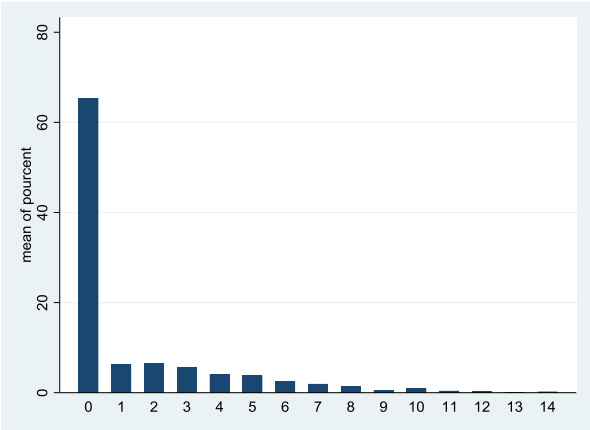


Figure 1: statistics for the eco-innovation score

3.3.2 The model: a *hurdle negative binomial model*

Since the variable to be explained is a discrete variable, we will estimate it using a counting model (Cameron and Trivedi, 2013). In this category of models, the Poisson model is the reference, but its use is conditioned by the equi-dispersion property of the Poisson distribution being satisfied, which is rarely the case in counting data. Negative binomial models are, therefore, used as they allow for overdispersion of the counts. Moreover, there might exist a population of 0 with heterogeneous characteristics, which leads to an excess of zeros. This corresponds to our situation because firms that do not eco-innovate may have various reasons not to. In this case, it is recommended that zeros and positive values be modelled separately (Cameron and Trivedi, 2013). Two large classes of models are used, according to the structure of the population in zeros. When zeros can be explained by a single process and this process introduces the idea of a hurdle to be crossed, it is recommended that a hurdle family model be used. On the other hand, if we assume that zeros are the result of two distinct processes, with “genuine” zeros on the one hand - i.e., individuals who will always remain at zero - and false zeros on the other - i.e., individuals who could have ended up with a positive value - we recommend using a zero-inflated model (Long and Freese, 2014). Insofar as all firms can potentially innovate environmentally and the survey takes into account a time step of 3 years to determine whether a company has innovated, we consider that a single process can explain the zeros. We therefore propose to use a hurdle regression model that combines a binary model to predict zeros and a zero-truncated regression model to predict nonzero counts (Long and Freese, 2014). With this type of model, it is possible to estimate the probability of being an eco-innovator, on the one hand, and to estimate the eco-innovation breadth, on the other.

For the hurdle model, we define the probability that Y takes the value

$$Pr(Y = y_i) = \begin{cases} \frac{e^{z_i\delta}}{1 + e^{z_i\delta}} = \pi_i & , \text{if } y_i = 0 \quad (1) \\ (1 - \pi_i) \frac{e^{x_i\beta}}{1 - e^{-e^{x_i\beta}}} & , \text{if } y_i > 0 \quad (2) \end{cases}$$

with a logit specification for zero values and a truncated negative binomial specification for positive values. π_i represents the probability of zero inflation. $e^{x_i\beta}$ is the intensity parameter, where X represents the p variables used to explain the propensity to innovate (x_i being the data vector for individual i) and β the p-dimensional vector of parameters to be estimated. In the logit model, Z represents the q variables used to explain the decision not to innovate (z_i being the data vector for observation i) and δ the q-dimensional vectors of parameters to be estimated. In the first equation, the aim is to explain the determinants of a firm's decision to eco-innovate. For this purpose, we introduce, in addition to the variables related to spatial externalities, control variables related to firms' internal characteristics and market and sectoral characteristics. To explain the breadth of eco-innovation (score from 1 to 14), we also introduce the variables related to firms' motivations to eco-innovate.

4. Results

Econometric models enable us to test the respective influence of different types of spatial externalities on the eco-innovative behavior of French industrial firms by controlling for their internal and external characteristics. We estimate a general model for all firms, and sub-models that allow for more in-depth analyses of externalities, depending on whether the firms are located in urban, peri-urban, or rural areas (see Table 3). We first present the results related to the types of externality (&4.1) and then the results by type of location area (&4.2).

4.1 Type of externality and eco-innovation in French manufacturing firms

We test the respective influence of the three types of externalities on firms' decision to eco-innovate, and the breadth of their eco-innovations, for all French manufacturing firms (general model) and according to firms' location area. Our results show differentiated effects of the three types of spatial externalities on firms' engagement in eco-innovation and on the breadth of their eco-innovation portfolio⁵.

In the general model, our results indicate that Marshallian externalities have a positive and significant effect on both engagement and breadth of the eco-innovative process of French industrial firms. The sub-models provide a more detailed description of the impact of specialization on eco-innovation and highlight differentiated results regarding Marshallian externalities. Specialization has a positive effect on the engagement in eco-innovative processes of rural and peri-urban firms, and a particularly positive effect on the breadth of eco-innovation of peri-urban firms. As far as urban firms are concerned, they do not appear sensitive to specialization externalities for eco-innovation, which has already been shown for other types of innovation (Magrini and Galliano, 2012). The results confirm (except for the urban model) our first hypothesis and are in line with the literature on Marshallian clusters

⁵ One could notice that this engagement and breadth aggregate the 14 types of environmental benefits (see table 2). We could test the impact of externalities only on engagement in eco-innovation for each of the 14 types of eco-innovation. We have selected a few results on specific types of eco-innovations that shed light on the results obtained with our general model. First, we confirm a significant positive effect of urban (12 out of 14 types) and peri-urban (9 out of 14) on eco-innovation engagement. For eco-innovations aiming at environmental benefits obtained during the production process, the engagement of firms in the two eco-innovations "Reduction of CO2 emissions per unit of output" and "Reduction of air, water, noise or soil pollution" is favored by specialization (as our model also shows), while the diversification externalities (related and unrelated) are not significant. The other results for these two types of eco-innovation are in line with the results of our model. For eco-innovations during the consumption process, the results are more contrasted. The eco-innovation aiming at a reduction in the amount of packaging waste is influenced by externalities in a similar way to our model. This eco-innovation develops regardless of the type of territory (no positive effect of urban or peri-urban areas). This is less the case for other eco-innovations aiming at an environmental benefit during the use of the product, where the agri-food industry is lagging behind. Another element to highlight for this type of eco-innovation concerns the positive impact of a local market, which tends to show that the proximity with the customer favors the engagement in eco-innovations related to the use of the product. The logit results are available upon request.

and districts, in that it highlights a positive role of specialization on firms' breadth of environmental innovations (Antonioli et al. 2016 ; Kebir et al. 2017).

Table 3: Engagement and breadth of eco-innovation - general model and models for each sub-population

	Total firms		Urban firms		Peri-urban firms		Rural firms	
	Choice	Breadth	Choice	Breadth	Choice	Breadth	Choice	Breadth
Location and spatial externalities								
Rural	Ref.	Ref.	-	-	-	-	-	-
Urban	0.27 ^{***}	0.066 ^{***}	-	-	-	-	-	-
Peri-urban	0.14 ^{***}	0.084 ^{***}	-	-	-	-	-	-
Specialisation	0.039 [*]	0.023 ^{**}	-0.042	0.0037	0.12 ^{**}	0.083 ^{***}	0.095 ^{**}	0.028
Related Variety	-0.27 ^{***}	0.10 ^{**}	-0.051	0.12 [*]	0.097	-0.18 ^{**}	-0.63 ^{***}	0.36 ^{***}
Unrelated Variety	0.11	-0.17 ^{***}	-0.20	-0.14	-0.41	-0.35 ^{**}	0.75 ^{***}	-0.33 ^{***}
Firm's internal characteristics								
Group	-0.11 ^{***}	0.081 ^{***}	-0.26 ^{***}	0.12 ^{***}	-0.24 ^{***}	0.078 ^{**}	0.28 ^{***}	0.039
Product innovation	1.26 ^{***}	0.14 ^{***}	1.39 ^{***}	0.17 ^{***}	1.43 ^{***}	0.16 ^{***}	0.97 ^{***}	0.0094
Process innovation	0.97 ^{***}	0.13 ^{***}	0.84 ^{***}	0.19 ^{***}	1.00 ^{***}	-0.014	1.30 ^{***}	0.078 [*]
Organizational innovation	1.53 ^{***}	0.12 ^{***}	1.58 ^{***}	0.16 ^{***}	1.47 ^{***}	0.098 ^{***}	1.50 ^{***}	0.080 ^{**}
Permanent R&D	0.66 ^{***}	0.16 ^{***}	0.75 ^{***}	0.14 ^{***}	0.73 ^{***}	0.25 ^{***}	0.40 ^{***}	0.14 ^{***}
Firm size :								
10-19	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
20-49	0.34 ^{***}	0.013	0.14 ^{***}	0.14 ^{***}	0.50 ^{***}	-0.22 ^{***}	0.65 ^{***}	0.080
50-249	0.73 ^{***}	0.0078	0.57 ^{***}	-0.026	1.12 ^{***}	-0.10 ^{**}	0.76 ^{***}	0.18 ^{***}
More than 250	1.15 ^{***}	0.22 ^{***}	1.11 ^{***}	0.21 ^{***}	1.42 ^{***}	-0.061	1.00 ^{***}	0.43 ^{***}
Firm's market and sectoral environment								
Adoption rate of eco-innovation in the area	-0.045	0.22 ^{***}	-0.52 ^{***}	0.62 ^{***}	-0.48 [*]	-0.0074	0.79 ^{***}	-0.29 ^{***}
Sector :								
Agri-food industry	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Equipment goods	-0.27 ^{***}	0.031	-0.12	0.092 ^{**}	-0.45 ^{***}	-0.067	-0.38 ^{***}	0.14 ^{**}
Transport	-0.70 ^{***}	0.12 ^{***}	-0.24 [*]	0.18 ^{***}	-1.44 ^{***}	0.062	-0.85 ^{***}	0.27 ^{***}
Others industrial products	-0.19 ^{***}	0.015	-0.14 [*]	0.085 ^{**}	-0.14	0.011	-0.24 ^{***}	-0.016
Main market :								
Local	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
National	-0.016	-0.035 [*]	-0.017	0.012	-0.017	-0.020	-0.063	-0.17 ^{***}
International	-0.024	-0.065 ^{***}	0.019	-0.053 [*]	-0.063	-0.036	0.13	-0.12 ^{**}
Motivations of eco-innovation								
Existing regulations	-	0.13 ^{***}	-	0.15 ^{***}	-	0.31 ^{***}	-	-0.097 ^{**}
Existing taxes	-	0.014	-	0.079 ^{***}	-	-0.082 ^{**}	-	0.084 [*]
Regulations or taxes expected	-	0.070 ^{***}	-	0.087 ^{***}	-	-0.038	-	0.066
Subsidies	-	-0.095 ^{***}	-	-0.14 ^{***}	-	-0.050	-	-0.052
Current or expected demand	-	0.14 ^{***}	-	0.16 ^{***}	-	0.080 ^{**}	-	0.16 ^{***}
Reputation	-	0.24 ^{***}	-	0.23 ^{***}	-	0.18 ^{***}	-	0.40 ^{***}
Voluntary actions for good practice	-	0.11 ^{***}	-	0.060 ^{**}	-	0.24 ^{***}	-	0.077 [*]
Cost : energy, water, materials		0.19 ^{**}		0.24 ^{***}		0.18 ^{**}		-0.011
Constant	-2.44 ^{***}	0.29 ^{***}	-1.74 ^{***}	-0.14	-2.00 ^{***}	1.03 ^{***}	-3.36 ^{***}	0.80 ^{***}
Lalpha	-	-1.62 ^{***}	-	-1.74 ^{***}	-	-1.81 ^{***}	-	-1.76 ^{***}
II	-11755.3	-19514.5	-6000.0	-10446.2	-2878.4	-4769.1	-2749.9	-4104.3
Chi2	10913.3	1862.0	5668.5	1371.2	2932.7	456.2	2503.6	382.1
N° Observations	4541	2052	2445	1202	1051	437	1045	413
weighted	26666	9248	13425	4944	6807	2287	6434	2017

t coefficients - * p<.10, ** p<.05, *** p<.01. Ref means reference class for the variables with different classes (size, sector...). Average marginal effects are presented in table A4.

Concerning unrelated diversification, our results show that it has a positive but non-significant effect on French firms' engagement in eco-innovation and a negative effect on the breadth of

their eco-innovations. These results differ from the existing literature on standard innovation, which shows that the existence of a diversity of knowledge bases has a global positive effect on innovation (Jacobs 1969, Beaudry and Shiffauerova 2009), and more precisely, a positive effect on their engagement in innovative processes and little influence on their innovation intensity (Galliano et al. 2015). The effect - positive or negative according to engagement or breadth in the eco-innovation process - is particularly significant in the case of rural firms. Thus, unrelated diversification has a positive and highly significant effect on rural firms' decision to eco-innovate and a negative effect on the breadth of their eco-innovations. The impact of Jacobian externalities tends to decline according to the importance of agglomeration effects. Thus, the negative effect of unrelated variety on firms' breadth of eco-innovations is also significant for peri-urban firms; and unrelated variety has no significant effect either on the engagement in or the breadth of eco-innovations of urban firms. These results tend to confirm our hypothesis 2, but they might highlight that too much diversification of activity has a negative effect on eco-innovation (Pei 2021).

Regarding related variety, the general model's results show that it negatively influences the process of engagement in eco-innovation and that it has a positive effect on the breadth of eco-innovations. This negative effect on the engagement process was unexpected and is observed for both urban firms (though its effect is non-significant) and rural firms. We observe that Related variety is not a determining factor in urban firms' engagement of eco-innovations, but it has a positive (though weakly significant) effect on the breadth of their environmental innovations, whereas the effect is negative for peri-urban firms. As for rural firms, results show that the effects of related variety also depend on engagement or breadth of their eco-innovation process. Indeed, related variety has a negative effect on engagement in eco-innovation but has a particularly strong and positive effect on the breadth of eco-innovations of rural firms. This result is in line with studies on innovation in peripheral areas,

which show that related variety tends to compensate for the low density and low variety of skills that characterize rural areas (Esparcia 2014; Naldi et al. 2015). It is a factor that contributes to the development of circular economy dynamics, which are strongly based on eco-innovation processes, and generally implies a large portfolio of eco-innovations (Cainelli et al. 2020; de Jesus et al. 2019).

Finally, our hypothesis 3 is only partially confirmed, in that related variety positively influences the breadth of eco-innovations of urban and rural firms but does not promote firms' engagement in eco-innovation.

4.2 Spatial externality and firms' location: urban, peri-urban and rural profiles

An analysis by type of location makes it possible to highlight different profiles of eco-innovation and territorial embeddedness, bearing in mind that non-spatial variables contribute to the diversity of eco-innovation factors depending on the firm's location.

Concerning urban firms, their eco-innovation behavior does not appear globally sensitive to spatial externalities. Whatever the nature of externality it seems that spatial externalities have no effect (besides a significantly low effect of related variety on breadth), on the engagement in and the breadth of eco-innovations of urban firms. This original result tends to highlight the fact that urban firms' eco-innovative behavior depends more on their internal resources and strategies than on the spatial externalities that exist in their area. It can also be influenced by the existence of greater opportunities of knowledge combinations generated by different types of externalities that coexist in urban areas. Similarly, the pressures experienced by urban firms to eco-innovate can be particularly intense and can have a wide variety of sources, which tends to highlight the very significant effects of all the motivations to eco-innovate. More particularly, we observe that the objective to reduce costs and to comply with existing and

expected regulations plays an important role in firms' breadth of environmental innovations, whereas subsidies for eco-innovation play a negative role. Thus, the range of motivations to eco-innovate seems to be narrower and more specific for peri-urban and rural firms. Furthermore, an urban firm's decision to eco-innovate is rather highly correlated with its product, process and, especially, organizational innovations. We observe a positive correlation between the breadth of environmental innovations and permanent R&D staff and being part of a group.

As for firms located in peri-urban areas, their profile is original. Their engagement in and breadth of eco-innovation are strongly correlated with Marshallian externalities. This positive impact of Marshallian effects on breadth is all the more important as unrelated and related varieties externalities have a negative effect. This can be explained by the specific profile of peri-urban areas, which can house production and logistics activities in proximity to urban centers. Regarding firms' internal resources, their decisions to eco-innovate are positively related to product innovation and associated with organizational changes, with no influence of demand and market dimension. Moreover, results show that this specialisation is strongly related to small and large firms. On the other hand, we observe no sectoral effect and firms in the agri-food industry do not differ significantly from the firms in other sectors, contrary to urban and rural firms, for which this sector has a negative effect. We also observe that, for peri-urban firms, as well as urban firms and unlike rural firms, the objective of cost reduction and of compliance with existing regulations plays an important role in the breadth of environmental innovations. This profile of peri-urban firms, which has been little studied, deserves further empirical investigation.

In the case of rural firms, spatial externalities have a strong influence on both their decision to eco-innovate and the breadth of their eco-innovations. This is more the case for rural firms than for urban and peri-urban firms, especially with regards to the engagement. In other

words, they present a profile opposite that of urban firms. This clearly highlights the fact that the nature of the spatial externalities can impact firms' eco-innovation behavior differently depending on whether they are located in a low vs. high density area. While Marshallian externalities have a highly positive and significant effect on their engagement in an eco-innovation process, we also find that unrelated variety externalities also play a positive role in the engagement, which is not the case for firms located in other types of areas. Moreover, we also find an unexpected negative effect of related variety on engagement, which may show that some rural firms do not have enough internal capabilities to capture these externalities. The engagement process of firms located in low density areas seems to depend more on Marshallian dynamics, or, on the contrary, on opportunities to take advantage of diversified knowledge and technologies that already exist in other firms located close by, but which belong to unrelated sectors. Once firms have engaged in eco-innovation, their breadth of eco-innovations is strongly correlated with a negative effect of unrelated variety. This effect is reinforced by the sensitivity of rural firms' eco-innovation breadth to the existence of related variety in their territory. As mentioned above, this profile of rural firms is in line with what empirical studies on rural and low-density areas have shown (Esparcia 2014; Galliano et al. 2019; Naldi et al. 2015). Concerning non-spatial variables, we find a strong correlation between the firm's size (medium/large) and the breadth of eco-innovations. A firm's decision to eco-innovate depends on its ability to mobilize internal resources to innovate (being part of a group, process and product innovations, organizational changes, etc.) whereas the breadth of its eco-innovations is more correlated to a critical size, to organizational changes and to the existence of a local market. The rate of eco-innovation adoption in the area also influences engagement in eco-innovation for rural firms, whereas the opposite is true for urban and peri-urban firms. This can be analyzed as rural firms having a greater tendency towards mimetic behavior. Finally, it is interesting to note that rural firms are not influenced by the same

motivations as other firms. Their breadth of eco-innovation is significantly influenced by their objective to meet demand requirements and by their desire to protect and enhance their reputation and image, particularly in local markets. Rural firms are less sensitive than peri-urban or urban firms to objectives of compliance to existing regulation and cost reduction.

5. Conclusion

This paper has aimed to characterize and test the effects of firms' spatial environment on their behavior in terms of eco-innovation, and in so doing to contribute to the extending of a "geography of eco-innovation". The aim was to analyze the role of the different types of spatial externalities highlighted in the literature (diversification, specialization and related variety) in the eco-innovative performance of industrial firms, and to highlight how the role of these externalities varies according to firms' location - urban, peri-urban and rural. This study is based on data from the Community Innovation Survey, which is representative of all French industrial sectors, and on administrative and social data (DADS), which have enabled us to measure externalities exhaustively by employment zone. One of our key hypotheses was that spatial externalities played an important role in a firm's behavior in terms of eco-innovation and that these externalities had a different impact depending on firms' location and impact differently firms' decision to engage in eco-innovation and the breadth of their eco-innovations. The results validate this hypothesis and provide analytical information. One of our major result is that spatial externalities have differentiated effects on eco-innovation according to firms' location and they impact firms' decision to engage in eco-innovation and the breadth of their eco-innovations differently. Another key result is related to the fact that rural firms' eco-innovation process strongly depends on spatial externalities, whereas the latter have almost no influence on urban firms' eco-innovation process. These findings

contribute to the Marshall versus Jacobs debate discussed in the literature (Beaudry and Schiffauerova 2009), by highlighting that each type of externality plays a different role according to engagement or breadth in the eco-innovation process and the location of the firm. As for related variety, and the effects of intersectoral complementarity and synergies that it involves, it has different effects depending on firms' location. It has a positive effect on the eco-innovation breadth of urban and rural firms, and is a driving factor, especially in the case of rural firms. Overall, specialisation and related variety tend to have a positive effect on firms' breadth of eco-innovations, which counterbalances the negative effect of a policy of unrelated diversification. This tends to confirm the benefit, highlighted in the literature, of a smart specialization of territories (Foray et al. 2009).

Our analysis, conducted in a comparative manner, for each type of location (urban, peri-urban, and rural), has enabled us to draw up profiles of eco-innovation behaviors that are useful in terms of defining public policies. The importance of spatial externalities, and particularly related variety in rural areas, calls for specific public actions supporting the development of networking between actors, to promote environmental innovation. Moreover, our analysis highlights the importance of organizational changes, the role of the local market on eco-innovation breadth (whatever the location), and the size of firms (small for peri-urban firms and large for rural firms) in the development of eco-innovation processes according to the location area. This is particularly important for this type of innovation, which is strongly related to regulation (and its anticipation) but also, as the results show, to concerns about reputation, compliance with sectoral codes of good practices or consumer demand.

We propose some avenues for future research. The profile of peri-urban firms, which has been little studied, deserves further empirical investigation, because peri-urban firms benefit both from their proximity to urban areas and their capacity to host production activities that are less constrained by population density. As for rural industrial firms, they deserve further

investigation to better understand what determines the dynamics of eco-innovation in peripheral areas, to identify what is related to internal dynamics versus what is related to firms' relationships with external actors. An in-depth qualitative analysis of the spatial processes of cooperation and resource capture of these rural firms deserves to be carried out.

Appendix

Table A1: Units and employees according to “A38” manufacturing industrial activities

A38	Division	Title	Number of units	Number of employees	Avg. Employees per unit
CA	10-12	Food and beverage	10,788	382,191	35.4
CB	13-15	Textile, wearing and leather	5,800	102,760	17.7
CC	16-18	Wood, paper and printing	12,162	186,708	15.4
CE	20	Chemical	2,669	143,787	53.9
CF	21	Pharmaceutical	587	78,707	134.1
CG	22-23	Rubber, plastic, non metallic	10,121	270,399	26.7
CH	24-25	Metal	17,053	384,709	22.6
CI	26	Computer, electronic, optic	2,481	129,283	52.1
CJ	27	Electrical equipment	2,211	114,283	51.7
CK	28	Machinery and equipment	5,114	178,716	34.9
CL	29-30	Transport equipment	2,588	363,319	140.4
CM	31-33	Furniture, other manufacturing	24,891	268,657	10.8
Total industry			96,465	2,603,519	27.0

Source: DADS 2014, INSEE

The category CD “Coke and refined petroleum”, which is made up 8838 employees in 70 plants, is not taken into account in our manufacturing industry analysis. We calculate the numbers of employees using full-time equivalent.

Table A2: Density and share of population and employment by type of areas in France

Type of area	Urban	Peri-urban	Rural	France
Population density (per km ²)	893.2	76.5	38.6	121.2
Employment density (per 1,000 residents)	479.1	241.8	347.4	399.4
Manuf. employment density (per 1,000 residents)	38.8	33.3	50.5	39.5
Total surface in km ² (share in %)	43,368 (8.0)	207,279 (38.1)	293,340 (53.9)	543,987 (100.0)
Total Population (share in %)	38,738,103 (58.8)	15,851,720 (24.1)	11,317,337 (17.2)	65,907,160 (100.0)
Total Employment (share in %)	18,558,997 (70.5)	3,833,111 (14.6)	3,931,872 (14.9)	26,323,980 (100.0)
Total manufacturing employment (share in %)	1,503,962 (57.8)	527,816 (20.3)	571,741 (22.0)	2,603,519 (100.0)

Source: RP2014 and DADS2014, INSEE. Data are for French metropolitan area.

Table A3: Definition of control variables

Control variables	Variables description
<i>Firm's internal characteristics</i>	
Group	= 1 if the firm is the subsidiary of a group, 0 if independent
Product Innovation	= 1 if the firm developed a product innovation, 0 otherwise
Process innovation	= 1 if the firm introduced a process innovation, 0 otherwise
Organizational innovation	= 1 if introduction of new business practices for organising procedures, new methods of organizing work responsibilities and decision making or new methods of organising external relations, 0 otherwise
Permanent R&D	= 1 if the firm has permanent R&D staff in-house, 0 otherwise
Firm size	Qualitative with 4 modalities: 10 to 19 employees (reference); 20 to 49; 50 to 249; and more than 250.
Adoption rate of eco-innovation in the area	Logarithm of the average rate of eco-innovation adoption by the firms of the same employment area
Sector	Qualitative with 4 modalities: Agri-food industry ; Equipment goods; Transport ;Others industrial products
Main market	Qualitative with 3 modalities: Regional market reference ; National market; Foreign market
<i>Motivations of eco-innovation</i>	
	= 1 if the firm introduced an environmental innovation in response (high or medium importance), 0 otherwise (low or not significant):
Regulation	- to existing environmental regulations
Taxes	- to existing environmental taxes, charges or fees
Regulation anticipated	- to environmental regulations or taxes expected in the future
Subsidies	- to government grants, subsidies or other financial incentives for environmental innovations
Demand	- to Current or expected market demand for environmental innovations
Reputation	- to improving enterprise's reputation
Codes of environmental good practices	- to voluntary codes or agreements for environmental good practices within the sector
Cost	- to high cost of energy, water or materials

Sources: CIS 2014 & DADS 2014

Acknowledgements : This research has been conducted with the support of the labex " SMS : Structuring Social Worlds" (ANR-11-LABX-0066) and of the project " Repro-Innov " (PSDR4-INRAE/Regional Council of Occitania).

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