ISSN: 1576-0162
DOI: http://dx.doi.org/10.33776/rem.vi66.8051

The Impact of Regulation on Environmental Performance: an Analysis for European Countries

El impacto de la regulación en el comportamiento medioambiental: un análisis sobre los países europeos

*Javier Lucena-Giraldo**
Universidad Autónoma de Madrid
javier.lucena@uam.es

Ernesto Rodríguez-Crespo
Universidad Autónoma de Madrid
ernesto.rodriguez@uam.es

Juan Carlos Salazar-Elena
Universidad Autónoma de Madrid
juancarlos.salazar@uam.es

Recibido: noviembre 2023; aceptado: enero 2024

Accésit Premio José Luis Sampedro, 2022

Abstract

This study provides new evidence on factors driving firms' eco-innovation in the European Union based on data from the Community Innovation Survey for the years 2008 and 2014 for eleven European countries. Firstly, our findings reveal that the propensity to eco-innovate changes over time. Secondly, the propensity to eco-innovate is unequally distributed across sectors, given that it is concentrated in a few sectors. Thirdly, we find that sectoral behavior is strongly influenced by the taxonomy of green sectors introduced by the European Union, since the propensity to innovate is higher in the carbon leakage taxonomy than in the mitigation and adaptation taxonomy. These results provide further insights into the sectoral factors driving eco-innovation diffusion. Moreover, these findings are relevant to increase environmental stringency, as they contribute to the diffusion of eco-innovation across sectors, especially in those that do not innovate.

Keywords: Eco-innovation, environmental regulation, Community Innovation Survey, European Union, probit regression.

* This research has received the second prize of the José Luis Sampedro Award. Comments and suggestions received during XXII Reuniones de Economía Mundial are gratefully acknowledged. Rodríguez-Crespo is grateful for the financial support received from Grant PID2022-138212NA-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by ERDF "A way of making Europe".

Resumen

En este estudio se han obtenido nuevas evidencias acerca de las empresas ecoinnovadoras en la Unión Europea, a partir de los datos de la encuesta de innovación comunitaria para los años 2008 y 2014 en once países europeos. En primer lugar, se ha observado que la propensión a ecoinnovar cambia con el tiempo. En segundo lugar, se ha verificado que la dicha propensión no se distribuye de forma simétrica en todos los sectores, de forma que se concentra en unos pocos. En tercer lugar, se ha constatado que el comportamiento sectorial depende en gran medida de la taxonomía de sectores verdes introducida por la Unión Europea, ya que la propensión media a innovar aumenta en la taxonomía de fuga de carbono con respecto a la de mitigación y adaptación. Estos resultados permiten profundizar en las características sectoriales que presenta la difusión de las ecoinnovaciones. Además, son relevantes para regulación medioambiental, ya que ayudan a difundir las ecoinnovaciones en todos los sectores, con especial atención en aquellos que no realizan actividades de innovadoras.

Palabras clave: Ecoinnovación, regulación medioambiental, Encuesta de Innovación Comunitaria, Unión Europea, regresión probit.

JEL Classification/ Clasificación JEL: O33, Q 55, Q 58.

1. Introduction

As the threats to natural resources and the environment have seriously increased, challenges to theory have grown apace, while economic policy debates have intensified (Rockström et al., 2009; Masson-Delmotte et al., 2021). This has motivated a new agenda for sustainable growth that copes with transition-related economic changes (Porter and Van der Linde, 1995; Nordhaus, 2017; Stern, 2022). Despite the controversies about the flaws in the models and market allocation, there is a broad consensus on a progressive shift of companies towards eco-innovation patterns. However, this process is alleged to be slow and complex, while institutional incentives have become increasingly important to facilitate this transition.

In the global context, Europe shows a prominent role in climate change issues due to the importance of emissions, a growing academic literature addressing these issues, and the institutional response by raising environmental stringency (Díaz García et al., 2015; Delgado et al., 2018). This fact has motivated the development of new concepts beyond environmental regulations (European Commission, 2019; Technical Expert Group (TEG), 2020a). In addition, it has resulted in the creation of specific taxonomies referring to sectors to be considered green, aiming to reallocate resources to sustainable activities.

Consequently, the transition to sustainable production is far from smooth and may entail a high degree of complexity for firms to accomplish this goal. Within this context, the concept of eco-innovation has emerged, where innovation contributes to developing new products and processes but is consistent with sustainable development in a broader sense (e.g., Díaz-García et al., 2015; Fernández et al., 2021). When firms engage in eco-innovation, they can be identified as green innovators by contributing to green growth and sustainable development and incentivized by economic policies. Such is the greening logic currently used by science, technology, and innovation in the redesign of recovering policies after the Russo-Ukrainian War (Ravet et al., 2022).

Despite remarkable academic efforts to shed light on the dynamics of eco-innovation, we acknowledge the presence of certain caveats in the academic literature. To begin with, most of the studies on eco-innovations rely on qualitative rather than quantitative evidence (Kiefer et al., 2017). It has been found that literature on eco-innovation is still in its early stages compared to innovation understood more broadly, and studies tend to focus on cross-sectional data and overlook the advantages of firms' improvements over time (Del Rīo et al., 2016). Although certain authors have emphasized the importance of environmental regulation to evaluate the performance of eco-innovators (e.g., Ambec et al., 2013; Fernández et al., 2021; Afeltra et al., 2023), studies that analyze eco-innovation diffusion and convergence are relatively scarce (Durán-Romero and Urraca-Ruiz, 2015; Han and Chen, 2021). This process of diffusion and convergence may be sensitive to the taxonomies of green sectors, since changes in such taxonomies may modify the propensity to eco-innovate. Finally, it is also reported that eco-innovation displays differences between sectors of activity (e.g., Diniz-Faria and Andersen, 2017; Shin et al., 2019; Zhang et al., 2020) and compared to general innovation (Halila and Rundquist, 2011). These prior topics have remained largely unexplored by previous studies and deserve further attention.

Drawing from previous studies, our objective is to fill specific gaps in the existing literature on eco-innovation. Firstly, we document the impact of regulation by evaluating whether eco-innovators' current performance is consistent with changes in green sectors' taxonomies. Secondly, we test whether diffusion patterns may be changing over time. Thirdly, we study the existence of differences between eco-innovators at the sectoral level or compared to general innovators. To accomplish our objectives, we use data from the Community Innovation Survey (henceforth, CIS) for a sample of 11 European countries for the years 2008 and 2014. By resorting to a probit regression, our results yield the following findings. Firstly, we find that the propensity to eco-innovate has a strong sectoral component and such a propensity is altered in terms of magnitude in 2014 compared to 2008. Secondly, the propensity to eco-innovate seems to depend strongly on sectoral taxonomies of green products, as the magnitude of the propensity is substantially altered for carbon leakage compared to mitigation and adaptation.

The remainder of this article is structured as follows. Section 2 analyses the conceptual framework, while section 3 presents the literature review. Section 4 sketches the empirical analysis, while section 5 describes the main results. Finally, section 6 is strictly focused on conclusions and policy implications.

2. The role of eco-innovation in sustainable development

The number and availability of indicators of the human impact on the environment has multiplied in recent decades. For example, the increase in CO_2 concentrations observed in parts per million has accelerated in recent decades, from 293 parts per million measured in 1866 to 317 in 1958, 387 in 2009, and 410 in 2020 (Meadows et al., 1972; Rockström et al., 2009; Masson-Delmotte et al., 2021). As a result, concerns about sustainability have increased and shifted from non-renewable resources to other topics such as climate change and low-carbon transition.

At the same time, interpretations of climate change have advanced from approaches to deal with externalities to integrated assessment models of economy and climate. However, controversies about potential flaws in the models, the market signals and their results are important, and substantial differences between paths arise (Nordhaus, 2017; Stern, 2022). Also, economic policy approaches have evolved to achieve sustainable development and the transition to a circular economy. For example, environmental regulations based on Pigouvian taxes gave way to the Porter hypothesis, where eco-innovation implemented as a consequence of increasing environmental stringency may lead firms to embed greater levels of productivity and competitiveness (Porter and Van der Linde, 1995; Ambec et al., 2013). This fact implies the evolution of policy instruments, such as carbon regulation, which shifted from tradable emissions permits to cap-and-trade emissions allowances.

In any case, directed technological change and innovation are at the forefront of the theoretical interpretations and proposals for environmental regulation (Acemoglu et al., 2012; Fagerberg, 2018). Therefore, our research is particularly interested in innovation oriented toward developing new products and processes consistent with sustainable development—that is, eco-innovation understood broadly (Díaz-García et al., 2015; Fernández et al., 2021). However, the analysis of eco-innovation may be complex, since there is neither a universal definition of eco-innovation nor a single element that links environmental sustainability and innovation.

Since many definitions of sustainability coexist, there are interconnected concepts such as green and clean products, environmental or green innovation, and eco-innovation, among others (De Jesus et al., 2018). As a consequence, analyzing eco-innovation could be misleading. In addition, we find no standard classifications of sustainability indicators, so debates on these issues persist (Park and Kremer, 2017; Saidani et al., 2019). In this regard, the problem lies in the differences in taxonomies and classifications.

Recent literature has identified and classified many drivers of eco-innovation, allowing us to distinguish technological, market and regulatory factors (Horbach et al., 2008, 2012). Technological drivers refer to one's own and the network's resources and capabilities. At the same time, market factors capture increases in demand related to environmental concerns and prices, while the regulatory framework includes determinants related to institutional pressures and public support (Del Rio et al., 2016; Fernández et al., 2021; Fichter and Clausen, 2021). In addition, certain differences have been identified in the relative importance of the factors, where we can cite the country's level of development, the type of eco-innovation, sector or firm size, among others. Nevertheless, most of the results on the diffusion of eco-innovations are sector-specific, and comparisons to other industries and generalizations are missing from the discussion.

2.1. Environmental regulation in the European Union

The impacts of climate change have been accelerating in recent decades, and a major institutional concern about the issue has been growing apace.

The proliferation of international cooperation agreements, such as the Kyoto Protocol, the Paris Agreement, or the 2030 Agenda for Sustainable Development of the United Nations, constitute an international agreement to coordinate an institutional response to face the challenges of sustainability and climate change. The European Union (hereafter EU) is aligned with these proposals and has promoted the diffusion of environmental sustainability and the transition to a low-carbon economy through specific legal initiatives. These comprise the EU's Emissions Trading System (EU ETS), the European Green Deal, the Just Transition Mechanism, or the goal of climate neutrality by 2050, among others.

Accordingly, the EU has introduced different sectoral taxonomies and classifications of green and sustainable sectors to develop these initiatives. These taxonomies and classifications define the different levels of environmental stringency, so companies need to consider these elements when implementing eco-innovations. From an institutional point of view, identifying these sectors is crucial as they can be considered targets to implement eco-innovation. At the same time, it is fundamental to understand that sectoral taxonomies cannot be considered static as they constantly evolve in line with changes in environmental policies.

This research considers two proposals and their corresponding taxonomies and classifications: the EU Emissions Trading System on low-carbon innovations of energy-intensive firms (henceforth EU ETS), and the EU Sustainable Financial Taxonomy (henceforth EU SFT). The EU ETS classification scheme used in the analysis is related to sectors deemed by the EU (European Commission, 2019) to be at risk of carbon leakage. The standard assessment of sectors at risk is based on the Carbon Leakage Indicator. This indicator is elaborated based on two dimensions: the intensity of EU trade with third countries and the intensity of emissions by sector. The first is calculated as the ratio of EU exports plus imports with third countries divided by the total EU market size, showing a certain resemblance to a trade openness degree. The second displays direct and indirect sectoral emissions divided by gross value added. If the indicator is above 0.2, the sector is considered at risk. In a nutshell, this is a cap-and-trade emissions allowance system introduced in 2005 whose caps have been reduced in different temporal phases.

In the EU SFT, each sustainable activity must contribute significantly to one of the objectives—mitigation, adaptation, water and marine resources, circular economy, pollution, biodiversity and ecosystems—either its own or facilitating others' performance (Regulation EU, 2020; TEG, 2020a). The consistency of the selection criteria is ensured because the activities may not be detrimental to the achievement of other objectives.

Mitigation activities have been selected for their major contribution to the stabilization of greenhouse gas emissions, either by their own means or by enhancing others, where we can include innovation (TEG, 2020b). Thus, eco-innovation activities are explicitly included in the taxonomy. For this reason, the economic activities of adaptation reduce either the adverse impact of climate or the risk of it. Likewise, these activities include reductions in the adverse impact (or its risk) via other activities.

Nevertheless, the EU SFT shows certain limitations. On the one hand, considering the mitigation objective, sectors with significant greenhouse gas emissions were selected first. Therefore, mitigation activities in these sectors were assumed to have more impact, but no alternatives were considered. On the other hand, the selection of adaptation activities is based on previous studies, which may not accurately reflect the current context and evolution of climate targets.

3. Literature review

Regulatory topics are growing in the literature on eco-innovations due to the importance of international agreements and policies. These can be considered a type of driver whose effectiveness is based on Porter's hypothesis. In this context, a more strict but flexible environmental regulation leads to increased competitiveness of eco-innovative firms, as certain studies have verified (Ambec et al, 2013; Horbach et al, 2012). Subsequent studies have softened the findings by either confirming the weak version of the hypothesis or nuancing the terms (Van Leeuwen and Mohnen, 2017; Bitat, 2018).

Environmental regulations are considered a macro, push-pull, external support driver, including institutional pressures and public support (Díaz Garcia et al., 2015; Fernández et al., 2021). However, studies provide contradictory results on the effect induced by institutional pressure. Some authors report a positive relationship between institutional pressure and eco-innovation, especially when the institutional pressure is higher (Hojnik and Ruzzier, 2016; Chang and Gotcher, 2020). In contrast, other works show that institutional pressure has a complementary or indirect effect, where green absorptive capacity becomes the key factor in the relationship (Wagner and Llerena, 2011; Madi et al., 2022). Regarding public support, Kanda et al. (2018) show the importance of the role played by intermediaries, while Polzin et al. (2016) point out specific coordination and integration failures in their analysis of financial support.

Furthermore, many studies evaluate the impact of environmental regulations and other potential eco-innovation drivers (Del Rio et al., 2016; Fernández et al., 2021). However, empirical studies comparing regulatory effects across taxonomies and classifications are missing from the analysis. This is particularly relevant because of the variety of definitions and taxonomies (Park and Kremer, 2017; Saidani et al., 2019). More specifically, we find no evidence linking eco-innovators' performance and green sector taxonomy. This leads us to the following research hypothesis:

H1: The current performance of eco-innovators depends on the taxonomy of green sectors considered

In addition to the impact exerted by regulation, academic literature has agreed on the importance of considering convergence in the diffusion of eco-innovation activities over time. Consequently, there may be asymmetric behavior of eco-innovation along the business cycle, where firms may implement different responses to eco-innovation. For example, while some firms may implement eco-innovation in the early phases of regulations, others may delay their decisions until the regulation is enforced.

However, we find scant evidence on this topic due to the difficulties associated with data availability. There are only exceptions. On the one hand, Durán-Romero and Urraca-Ruiz (2015) use patent data adoption during the period 1978–2010 for a sample of developed and developing countries. They find a different impact of drivers of eco-innovation efforts, as the regulation only spurs eco-innovation in developed countries. On the other hand, Han and Chen (2021) focus on eco-innovation drivers of firms located in Myanmar. Although their study departs from a cross-sectional basis, they find how firms' working experience of at least five years improves the probability of eco-innovating, indirectly suggesting the importance of time to shape eco-innovation efforts. In line with this strand of literature, we acknowledge the importance of time and formulate a second research hypothesis:

H2: Eco-innovations can be diffused over time to help eco-innovators benefit from convergence

Finally, it is important to acknowledge that the diffusion of eco-innovations takes place over time, but at the same time, it cannot be considered homogeneous. To this end, it is found that sectors of economic activity present substantial differences in the diffusion patterns of eco-innovations. Academic scholars have mainly followed two approaches to deal with this specificity to identify such differences across eco-innovators. The first strand of literature has isolated the study of the effect of eco-innovations in a specific sector to provide a deeper analysis by focusing on either the automotive (Diniz-Faria and Andersen, 2017; Shin et al., 2019; Phirouzabadi et al., 2020), manufacturing (Cainelli et al., 2015), forestry (Štěrbová et al., 2017), or even services (Desmarchelier et al., 2013) sectors. Although this analysis provides a general sectoral glimpse, it makes it unfeasible to do cross-sectoral comparisons.

The second approach has shifted to a comparative analysis of eco-innovators. A set of studies compares eco-innovators with general innovators. Halila and Rundquist (2011) performed an analysis for Sweden and found that both perceptions and behavior can explain differences between eco-innovators and general innovators. Other authors have attempted to find significant differences between eco-innovators for different sectors of economic activity. Jové-Llopis and Segarra-Blasco (2018) obtained differences between manufacturing and services eco-innovators from Spain, where they found significant differences across types of services. More recently, Zhang et al. (2020) explored differences in eco-innovation between firms using data from Fortune Global 500. The authors allege substantial asymmetries concerning the type of industry, since companies already using eco-innovations are more environmentally concerned than other types of firm. All these studies report that the characteristics of eco-innovation strongly vary by firm and sector.

Still, it is necessary to shed light on additional evidence using a higher level of sectoral disaggregation. Accordingly, we formulate a final research hypothesis:

H3: The performance of eco-innovators differs by sector

4. Empirical analysis

4.1. Data

The data source used is the CIS database. This is the most comprehensive innovation survey in Europe and is carried out by the European Commission. It provides harmonized microdata that can be sorted according to different criteria, such as country or type of innovation. Overall, the CIS allows us better to understand innovation and differences across agents, which is why we select it for the baseline data. More recently, the CIS has begun introducing questions on how firms conduct eco-innovation activities, allowing researchers to shed light on these patterns beyond innovation. The sample contains eleven European countries for two crossed-yearly sections, 2008 and 2014. Countries have been selected based on their CIS data availability, since the research objective requires a high level of disaggregation of economic activity by sector to ensure consistency. Tables A1, A2, and A3 in the Appendix show, respectively, National Association of Colleges and Employers (NACE) codes for each sectoral classification used in the analysis and the main descriptive statistics for explanatory variables.

We find important concerns contingent on data issues. Firstly, CIS data are collected every two years, and the sample of years may be considered short for disaggregation purposes. This data paucity thus impedes us from using panel data techniques to evaluate the effect of the business cycle. Secondly, the most recent year reported in the CIS is 2014. Although this coincides with the first list of carbon leakage taxonomy, further years of such taxonomy and others implemented in subsequent years are not covered and this may be considered a major shortcoming. However, these data can help evaluate whether eco-innovators' current performance is resilient to further changes in the taxonomy of green sectors by comparing two cross-sections of years.

4.2. Methodology

We analyze the propensity to eco-innovate using a binary choice model, as highlighted in previous studies (e.g., Jové-Llopis and Segarra-Blasco, 2018; Fernández et al., 2021). The dependent variable is a control variable that takes a value of 1 where the firm is an eco-innovator, and 0 otherwise. This analysis presents a major advantage compared to linear regression, since the assumptions required to create a causal relationship are relaxed, and results are interpreted as linear probabilities (Hair et al., 2009). We consider the results between years by types of indicator to see differences, and the results strongly support hypothesis H2. We also analyze several indicators of eco-innovations but disaggregated by sectors of economic activity, the results being aligned with hypothesis H3. To corroborate the previous hypothesis and H1, we followed a quantitative perspective. To this extent, we implement a probit regression disaggregated by sector for 2008 and 2014. To test the consistency and accuracy of the results, we perform three different regression models, altering the influence of structural factors.

5. Results

Firstly, we focus on the existence of substantial differences across the period of analysis. Table 1 compares the evolution of specific eco-innovation indicators in 2008 and 2014.

According to Table 1, indicators report differences between years in the propensity to eco-innovate by types of indicator. Among indicators, we find a general decrease in the number of enterprises reducing air and noise from 32.3 percent to 25.2 percent, while those mitigating the carbon footprint decreased from 32.9 percent to 24.7 percent. Other eco-innovation activities, such as the reduction of energy use per unit of output, remained fairly stable.

The results from Table 1 support H2, as firms have changed their propensity to perform eco-innovation activities over time and firms' current eco-innovation behavior seems to be highly influenced by its previous behavior (Durán-Romero and Urraca-Ruiz, 2015; Jové-Llopis and Segarra-Blasco, 2018). Although the differences reported are downward based and may contradict the outcomes expected from the academic literature, they are highly influenced by the years of the sample. In fact, this period is contingent on the global financial crisis, which forced firms' willingness to invest in innovation-related activities (Archibugi et al., 2013a, 2013b). Many European countries were affected by

Table 1. Evolution of eco-innovation propensity by type in 2008 and 2014, percentage

Type of eco-innovation	2008	2014
Enterprises that reduced material or water use per unit of output within the enterprises by innovating	28.0	26.1
Reduced energy use per unit of output	32.8	32.8
Enterprises that replaced a share of materials with less polluting or hazardous substitutes within the enterprises by innovating	22.7	18.6
Enterprises that reduced air, water, noise or soil pollution within the enterprises by innovating	32.3	25.2
Enterprises that recycled waste, water, or materials for own use or sale within the enterprises by innovating	33.5	20.7
Enterprises that reduced energy use or CO2 'footprint' during the consumption or use of a good or service by the end user, by innovating	32.9	24.7
Enterprises that reduced air, water, noise or soil pollution during the consumption or use of a good or service by the end user, by innovating	28.7	17.8
Enterprises that facilitated recycling of product after use by the end user, by innovating	25.8	15.6

Source: CIS data, European Commission.

an economic recession, dampening innovation; however, it may be expected that firms will invest more in innovation after the recovery. Although the last year with available CIS statistics is 2014, other indicators allow us to trace the eco-innovation trend. Data from the European Eco-innovation Scoreboard report significant changes, since the index for Luxembourg as the leader country increased from 162 to 171 in 2021 compared to 2014. The last ranked country is Bulgaria, but the index rose significantly from 33 to 50 in the same period. Accordingly, we find that eco-innovation patterns are increasing over time despite the sharp decline experienced after the global financial crisis.

We now analyze whether eco-innovation diffusion presents a sectoral pattern. As in Table 1, we analyze several indicators of eco-innovations disaggregated by sectors of economic activity. According to Table A4 (available in the Appendix), we find differences in eco-innovation propensity by type of indicator and sector. Additionally, noticeable differences in growth rates are observed for sectors with positive growth rates. The main findings, which are aligned with hypothesis H3, can be summarized as follows. We find that many sectors have increased their propensity to eco-innovate by reducing materials or water use, as shown in column 1. This is in line with the principles of the circular economy strategy, which has been gaining importance in European environmental policy. Also, we find that sectoral behavior is based on growing the propensity to eco-innovate in two or three indicators, confirming that firms eco-innovate by following specific targets. Finally, only sectors 55 and 56 have increased their propensity to eco-innovate in parallel for all indicators, confirming our previous findings that eco-innovations are concentrated in many industries (Diniz-Faria and Andersen, 2017; Shin et al., 2019).

To corroborate the previous hypotheses together with H1, we have followed a quantitative perspective. To this end, we implement a probit regression disaggregated by sector for 2008 and 2014. To test the consistency and accuracy of the results, we perform three regression models, altering the influence of structural factors. Model 1 assumes no influence exerted by other factors, while model 2 introduces controls for firm size, research and development, cooperation, and public funding. Finally, model 3 assumes identical controls to model 2 but also includes country fixed effects.

Marginal effects of probit regression are reported in Table A5 (available in the Appendix). Firstly, we find sectoral differences concerning the propensity to eco-innovate, as the marginal effects differ across sectors. The coefficients present substantial variation and range from -0.332 (sectors 64–66, column 5) to 0.228 (sectors 36–39, column 1). In addition, we find many cases where statistical probability is not significant. Secondly, this sectoral pattern holds across sectors when classified following a specific taxonomy. For the case of the carbon leakage classification, the average propensity for sectors to eco-innovate registered a sharp increase from 2008 to 2014, while it tends to decrease when we consider sectors under the mitigation taxonomy.[1] Thirdly, there seem to be changes over time in the propensity to eco-innovate, as the magnitude of the coefficients is altered. Although there are some cases where the level of significance changes between 2008 and 2014, the magnitudes differ slightly in contrast to the sign. In 2008, being from a specific sector was associated with an increase or decrease in the propensity to eco-innovate, and the same pattern persisted in 2014. Fourthly, the propensity to eco-innovate registers slight changes when we introduce structural characteristics, although marginal effects are not substantially altered in terms of magnitude and significance.

These results contribute to shed light on patterns of eco-innovating firms. We find that the diffusion of eco-innovations is highly influenced by the business cycle (Durán-Romero and Urraca, 2015; Jové-Llopis and Segarra-Blasco, 2018), but at the same time, being from a specific sector does not transform the direction of the propensity to eco-innovate. This is in line with research hypothesis H2. Also, the propensity to eco-innovate is highly influenced by the sector of economic activity; however, it is not concentrated solely in a specific sector but in various sectors from different fields of activity, confirming research hypothesis H3. Finally, in relation to previous studies, we put aside the existence of changes in the propensity to eco-innovate under different taxonomies: the propensity to eco-innovate increases for firms classified under carbon leakage more than for those classified under mitigation. This may be explained by multinational enterprises' increasing environmental awareness (e.g., Aithal, 2017), since they have to operate in countries with different degrees of environmental stringency, forcing them to diversity their strategies. These results are in line with research hypothesis H1.

6. Conclusions

This study has helped to shed light on eco-innovation patterns for the EU by following a quantitative perspective. Using CIS data for eleven European countries in 2008 and 2014, we report significant findings for the propensity to eco-innovate. Firstly, eco-innovation activities depend strongly on the business cycle, as firms re-adapt their production processes to accommodate clean technologies. Secondly, we find that the propensity to eco-innovate is concentrated in a reduced number of sectors. Additionally, firms within a particular sector do not experience a shift in the inclination to eco-innovate from increasing to decreasing or vice versa. Thirdly, the propensity to eco-innovate depends on the taxonomy of the green sectors considered, where

1 Mean propensities are reported for carbon leakage, models 1 (0.05 in 2008 and 0.11 in 2014), 2 (0.05 in 2008 and 0.08 in 2014), and 3 (0.00 in 2008 and 0.08 in 2014); and for mitigation, models 1 (0.07 in 2008 and -0.04 in 2014), 2 (0.03 in 2008 and -0.02 in 2014), and 3 (-0.04 in 2008 and -0.06 in 2014).

carbon leakage shows more prominent incentives for further improvements than mitigation.

These results indicate the need for policy action. In a context shaped by the Russo-Ukrainian War, firms need to set a path of recovery by triggering their growth and competitiveness. Innovation drivers strengthen cooperation and peace (Ravet et al., 2022). More specifically, investments in eco-innovation seem to be a long-term alternative for European countries to decrease their dependency on foreign energy resources. In the context of the EU, where a toxic-free environment is a must, different institutional incentives may exist across all sectors for firms that conduct eco-innovation. The Next Generation European Union Recovery Plan established for Europe shall not just highlight the importance of green innovation itself but set specific targets and objectives to be reached by firms. To this end, the taxonomies of green sectors may have a pivotal role to identify which specific sectors conduct eco-innovation, but this classification may not be considered exhaustive and may be opened to include other sectors for policy purposes.

Among the major limitations of our study, it should be noted that the CIS has only been carried out for a small number of years. Therefore, it is not possible to undertake a continuous assessment that would show the evolution of the propensity to eco-innovate through firms' further improvements. As a result, future studies may be expected to explore other data sources to complement this analysis. In addition, this research could be extended to investigate the behavior and interaction of different eco-innovation drivers. This could enable us to explore the potential existence of trade-offs between different explanatory factors.

References

Acemoglu, D.; Aghion, P.; Bursztyn, L.; and Hemous, D. (2012). The Environment and Directed Technical Change. *American Economic Review*, 102 (1), 131–166.

Afeltra, G., Alerasoul, S. A., and Strozzi, F. (2023). The Evolution of Sustainable Innovation: From the Past to the Future. *European Journal of Innovation Management*, 26 (2), 386–421.

Aithal, P. S. (2017). Impact of Domestic, Foreign, and Global Environments on International Business Decisions of Multinational Firms: A Systematic Study. *International Journal of Management, Technology, and Social Sciences (IJMTS)*, *2* (2), 93–104.

Ambec, S., Cohen, M. A., Elgie, S., and Lanoie, P. (2013). The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness? *Review of environmental Economics and Policy*, 7 (1), 2–22.

Archibugi, D., Filippetti, A., and Frenz, M. (2013a). The Impact of the Economic Crisis on Innovation: Evidence from Europe. *Technological Forecasting and Social Change*, *80*(7), 1247–1260.

Archibugi, D., Filippetti, A., and Frenz, M. (2013b). Economic Crisis and Innovation: Is Destruction Prevailing Over Accumulation? *Research Policy*, *42*(2), 303–314.

Bitat, A. (2018). Environmental Regulation and Eco-innovation: the Porter Hypothesis Refined. *Eurasian Business Review,* 8, 299–321.

Bucher, H., Drake-Brockman, J., Kasterine, A., and Sugathan, M. (2014). *Trade in Environmental Goods and Services: Opportunities and Challenges*. Geneva: International Trade Centre Technical Paper.

Cainelli, G., De Marchi, V., and Grandinetti, R. (2015). Does the Development of Environmental Innovation Require Different Resources? Evidence from Spanish Manufacturing Firms. *Journal of Cleaner Production*, *94*, 211–220.

Chang, K. H., and Gotcher, D. F. (2020). How and When Does Co-production Facilitate Eco-innovation in International Buyer-Supplier Relationships? The Role of Environmental Innovation Ambidexterity and Institutional Pressures. *International Business Review,* 29(5), 101731.

De Jesus, A., Antunes, P., Santos, R., and Mendonça, S. (2018). Eco-innovation in the Transition to a Circular Economy: An Analytical Literature Review. *Journal of Cleaner Production*, 172, 2999–3018.

Del Río, P., Peñasco, C., and Romero-Jordán, D. (2016). What Drives Eco-innovators? A critical Review of the Empirical Literature Based on Econometric Methods. *Journal of Cleaner Production*, *112*, 2158–2170.

Delgado, M. J., Ares, A. C., and de Lucas Santos, S. (2018). Cyclical Fluctuation Patterns and Decoupling: Towards Common EU-28 Environmental Performance. *Journal of Cleaner Production*, *175*, 696–706.

Desmarchelier, B., Djellal, F., and Gallouj, F. (2013). Environmental Policies and Eco-innovations by Service Firms: An Agent-based Model. *Technological Forecasting and Social Change*, *80*(7), 1395–1408.

Díaz-García, C., González-Moreno, Á., and Sáez-Martínez, F. J. (2015). Eco-innovation: Insights from a Literature Review. *Innovation*, *17*(1), 6–23.

Diniz-Faria, L. G., and Andersen, M. M. (2017). Sectoral Patterns Versus Firm-level Heterogeneity. The Dynamics of Eco-innovation Strategies in the Automotive Sector. *Technological Forecasting and Social Change*, *117*, 266–281.

Durán-Romero, G., and Urraca-Ruiz, A. (2015). Climate Change and Eco-innovation. A Patent Data Assessment of Environmentally Sound Technologies. *Innovation*: *Organization and Management, 17*(1), 115–138.

European Commission (2019). *Commission Delegated Decision Supplementing Directive 2003/87/EC of the European Parliament and of the Council Concerning the Determination of Sectors and Subsectors Deemed at Risk of Carbon Leakage for the Period 2021 to 2030, (EU) 2019/708*. European Commission, Brussels.

Fagerberg, J (2018). "Mission (Im)possible? The Role of Innovation (and Innovation Policy) in Supporting Structural Change and Sustainability Transitions," *Working Papers on Innovation Studies, Centre for Technology, Innovation and Culture, University of Oslo*, 20180216.

Fernández, S., Torrecillas, C., and Labra, R. E. (2021). Drivers of Eco-innovation in Developing Countries: the Case of Chilean Firms. *Technological Forecasting and Social Change*, *170*, 120902.

Fichter, K., and Clausen, J. (2021). Diffusion of Environmental Innovations: Sector Differences and Explanation Range of Factors. Environmental Innovation and Societal Transitions, 38, 34–51.

Grazzi, M., Sasso, S. and Kemp, R. (2019). A Conceptual Framework to Measure Green Innovation in Latin America and the Caribbean. *IDB-DP discussion paper 730*.

Halila, F., and Rundquist, J. (2011). The Development and Market Success of Eco-innovations: A Comparative Study of Eco-innovations and "Other" Innovations in Sweden. *European Journal of Innovation Management*, 14(3), 278-302.

Han, M. S., and Chen, W. (2021). Determinants of Eco-innovation Adoption of Small and Medium Enterprises: An Empirical Analysis in Myanmar. *Technological Forecasting and Social Change*, *173*, 121146.

Hair, J. F., Black, W., and Babin, N. (2009). *Multivariate Data Analysis.* Pearson, New Jersey.

Hojnik, J., and Ruzzier, M. (2016b). The Driving Forces of Process Eco-innovation and Its Impact on Performance: Insights from Slovenia. Journal of Cleaner Production, 133, 812–825.

Horbach, J. (2008). Determinants of Environmental Innovation—New Evidence from German Panel Data Sources. *Research policy,* 37(1), 163–173.

Horbach, J., Rammer, C., and Rennings, K. (2012). Determinants of Eco-innovations by Type of Environmental Impact. The Role of Regulatory Push/Pull, Technology Push and Market Pull. *Ecological Economics*, 78, 112–122.

Jové-Llopis, E., and Segarra-Blasco, A. (2018). Eco-innovation Strategies: A Panel Data Analysis of Spanish Manufacturing Firms. Business Strategy and the Environment, 27(8), 1209–1220.

Kanda, W., Hjelm, O., and Bienkowska, D. (2014). Boosting Eco-innovation: The Role of Public Support Organisations. In XXV ISPIM Conference on Innovation for Sustainable Economy and Society, Dublin, Ireland, June 8-11, 2014.

Kiefer, C. P., Carrillo-Hermosilla, J., Del Río, P., and Barroso, F. J. C. (2017). Diversity of Eco-innovations: A Quantitative Approach. *Journal of Cleaner Production*, *166*, 1494–506.

Mady, K., Abdul Halim, M. A. S., Omar, K., Abdelkareem, R. S., and Battour, M. (2022). Institutional Pressure and Eco-innovation: The Mediating Role of Green Absorptive Capacity and Strategically Environmental Orientation Among Manufacturing SMEs in Egypt. *Cogent Business and Management,* 9(1), 2064259.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... and Zhou, B. (2021). Climate Change 2021: the Physical Science Basis.

Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Meadow, D. H.; Meadow, D.; Randers, J.; and Behrens, W. W. (1972). The Limits to Growth: a Report to the Club of Rome. Universe Books United States of America.

Nordhaus, W. (2017). Social Cost of Carbon in DICE Model. *Proceedings of the National Academy of Sciences*, 114 (7), 1518–1523.

OECD (2021). *How Will COVID-19 Reshape Science, Technology and Innovation? OECD Policy Responses to Coronavirus (COVID-19).* Organisation for Economic Cooperation and Development, Paris.

Phirouzabadi, A. M., Juniper, J., Savage, D., and Blackmore, K. (2020). Supportive or inhibitive? Analysis of dynamic interactions between the inter-organisational collaborations of vehicle powertrains. *Journal of Cleaner Production*, *244*, 118790.

Park, K., and Kremer, G. E. O. (2017). Text Mining-Based Categorisation and User Perspective Analysis of Environmental Sustainability Indicators for Manufacturing and Service Systems. *Ecological Indicators*, 72, 803-820.

Polzin, F., von Flotow, P., and Klerkx, L. (2016). Addressing Barriers to Eco-innovation: Exploring the Finance Mobilisation Functions of Institutional Innovation Intermediaries. Technological Forecasting and Social Change, 103, 34-46.

Porter, M. E., and Van der Linde, C. (1995). Toward a New Conception of the Environment-competitiveness Relationship. *Journal of Economic Perspectives*, *9*(4), 97–118.

Ravet, J., Di Girolamo, V., Mitra, A., Peiffer-Smadja, O., Canton, E., Hobza, A. (2022). *EU Research and Innovation and the Invasion of Ukraine: Main Channels of Impact.* European Commission, Brussels.

Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F. S.; Lambin, E. F.; ... and Foley, J. A. (2009). A Safe Operating Space for Humanity. *Nature*, 461(7263), 472-475.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., and Kendall, A. (2019). A Taxonomy of Circular Economy Indicators. *Journal of Cleaner Production*, 207, 542-559.

Shin, J., Hwang, W. S., and Choi, H. (2019). Can Hydrogen Fuel Vehicles Be a Sustainable Alternative on Vehicle Market?: Comparison of Electric and Hydrogen Fuel Cell Vehicles. *Technological Forecasting and Social Change*, *143*, 239–248.

Štěrbová, M., Výbošťok, J., and Šálka, J. (2021). A Classification of Eco-innovators: Insights from the Slovak Forestry Service Sector. *Forest Policy and Economics*, *123*, 102356.

Stern, N. (2022). A time for Action on Climate Change and a Time for Change in Economics. *The Economic Journal*, 132 (644), 1259-1289

Technical Expert Group (TEG) (2020a). Taxonomy: Final Report of the Technical Expert Group on Sustainable Finance.

Technical Expert Group (TEG) (2020b). Taxonomy Report: Technical Annex. Updated Methodology and Updated Technical Screening Criteria.

Van Leeuwen, G., and Mohnen, P. (2017). Revisiting the Porter Hypothesis: an Empirical Analysis of Green Innovation for the Netherlands. Economics of Innovation and New Technology, 26(1-2), 63-77.

Wagner, M., and Llerena, P. (2011). Eco-innovation Through Integration, Regulation and Cooperation: Comparative Insights from Case Studies in Three Manufacturing Sectors. Industry and Innovation, 18(8), 747-764.

Zhang, L., Zhao, S., Cui, L., and Wu, L. (2020). Exploring Green Innovation Practices: Content Analysis of the Fortune Global 500 Companies. *SAGE Open*, *10*(1), 1–13.

Annex

Table A1. Descriptive statistics by type of eco-innovation

	2008	2014
Enterprises that reduced material or water use per unit of output within the enterprises by innovating	0.567	0.462
Reduced energy use per unit of output	0.305	0.211
Enterprises that replaced a share of materials with less polluting or hazardous substitutes within the enterprises by innovating	0.250	0.164
Enterprises that reduced air, water, noise or soil pollution within the enterprises by innovating	0.315	0.212
Enterprises that recycled waste, water, or materials for own use or sale within the enterprises by innovating	0.343	0.244
Enterprises that reduced energy use or CO2 'footprint' during the consumption or use of a good or service by the end user, by innovating	0.374	0.272
Enterprises that reduced air, water, noise or soil pollution during the consumption or use of a good or service by the end user, by innovating	0.249	0.154
Enterprises that facilitated recycling of product after use by the end user, by innovating	0.221	0.148
Size (natural logarithm of sales)	15.222	15.500
RandD efforts	0.334	0.361
Collaboration	0.279	0.270
Public funds	0.144	0.237

Source: Authors own elaboration with CIS data.

Table A2. Descriptive statistics by type of sector

	2008	2014
10_12	0.080	0.065
13_15	0.066	0.049
16_18	0.057	0.043
19_23	0.100	0.090
24_25	0.074	0.067
26_30	0.124	0.129
31_33	0.061	0.051
35	0.017	0.013
36_39	0.032	0.023
41_43	0.019	0.003
45_47	0.122	0.996
49_51	0.036	0.028
52_53	0.024	0.019
58_60	0.017	0.018
61_63	0.052	0.055
64_66	0.044	0.039
69_70	0.009	0.010
71_73	0.049	0.044
74_75	0.002	0.004
77_82	0.014	0.152

Note: Sectors are sorted by NACE code.
Source: Authors own elaboration with CIS data.

Table A3. Descriptive statistics by country

	2008	2014
Bulgaria	0.170	0.159
Cyprus	0.022	0.026
Czech Republic	0.143	0.118
Germany	0.146	0.223
Estonia	0.090	0.028
Hungary	0.065	0.087
Lithuania	0.024	0.057
Latvia	0.014	0.027
Portugal	0.153	0.186
Romania	0.139	0.056
Slovakia	0.034	0.033

Source: Authors own elaboration with CIS data.

Table A4. Evolution of eco-innovation propensity by type and industry

NACE Code	Enterprises that reduced material or water use	Enterprises that reduced energy use	Enterprises that replaced materials with less polluting substitutes	Enterprises that reduced air, water, noise or soil pollution	Enterprises that recycled waste, water, or materials for own use or sale	Enterprises that reduced energy use (user)	Enterprises that reduced air, water, noise or soil pollution (user)	Enterprises that facilitated recycling of product after use
10_12	↑		↑					
13_15	↑			↑				
16_18								
19_22	↑	↑	↑					
23	↑	↑						
24_30								
31_33								
35	↑↑↑	↑↑				↑↑		
36_39	↑↑↑		↑					
41_43	↑↑↑							
45_47	↑↑↑			↑↑↑				
49_53	↑	↑↑						
55_56	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑	↑↑↑	↑↑↑	↑↑↑
58_63								
64_66		↑↑↑		↑↑↑			↑↑↑	
69_75								

Note: The symbols "↑", "↑↑", and "↑↑↑" stand for a positive growth rate lower than 10%; lower than 20%, and higher that 20%, respectively.
Source: Authors own elaboration with CIS data.

TABLE A5. MARGINAL EFFECTS OF THE EVOLUTION OF ECO-INNOVATION PROPENSITY ESTIMATED BY A PROBIT REGRESSION, 2008 AND 2014

Explanatory variables	Model 1		Model 2		Model 3	
	2008	*2014*	*2008*	*2014*	*2008*	*2014*
Nace Code:						
13_15(i)	-0.107***	-0.009	-0.035**	-0.006	-0.076***	-0.034*
16_18(i)	0.076***	0.158***	0.083***	0.149***	0.022	0.094***
19_23(i)	0.132***	0.160***	0.082***	0.081***	0.031**	0.056***
24_25(i)	0.105***	0.136***	0.085***	0.097***	0.014	0.059***
26_30	0.138***	0.126***	0.049***	0.015	-0.001	-0.001
31_33	0.011	0.049**	0.025*	0.028	-0.027*	-0.018
35(ii)	0.177***	0.032	0.104***	-0.012	0.054**	-0.022
36_39(ii)	0.228***	0.153***	0.200***	0.145***	0.102***	0.082***
41_43(ii)	0.130***	-0.063	0.112***	-0.062	0.011	-0.151***
45_47	-0.098***	-0.096***	-0.088***	-0.081***	-0.134***	-0.109***
49_51(ii)	0.003	0.0614***	0.016	0.079***	-0.042**	0.032
52_53	-0.073***	-0.061**	-0.091***	-0.069***	-0.150***	-0.116***
58_60	-0.191***	-0.198***	-0.195***	-0.205***	-0.263***	-0.247***
61_63(ii)	-0.212***	-0.182***	-0.261***	-0.246***	-0.311***	-0.248***
64_66	-0.222***	-0.162***	-0.285***	-0.184***	-0.332***	-0.218***
69_70	-0.169***	-0.126***	-0.142***	-0.111***	-0.283***	-0.210***
71_73	-0.049***	-0.017	-0.088***	-0.086***	-0.175***	-0.123***
74_75	0.034	-0.044	0.040	-0.072	-0.123**	-0.202***
77_82	-0.011	-0.007	0.016	-0.039***	-0.104***	0.009
Intercept	0.559***	0.440***	0.581***	0.478***	0.636***	0.495***
Size controls	N	-	Y	Y	Y	Y
RandD controls	N	-	Y	Y	Y	Y
Collabora-tion effects	N	-	Y	Y	Y	Y
Public funds effects	N	-	Y	Y	Y	Y
Country effects	N	N	N	N	Y	Y
Num. of obs.	27,292	21,808	27,054	21,764	27,054	21,764
Pseudo-R2	0.0463	0.0349	0.1125	0.0767	0.1744	0.1278

Note: The marginal effects by industry take the Food, beverages and tobacco sector as a reference. The symbols (***), (**) and (*) stand for 99%, 95% and 90% confidence, respectively. (i) considers NACE codes associated with carbon leakage, while (ii) refers to mitigation.
Source: Authors own elaboration with CIS data.