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Review

Eco-innovation across SMEs in European macro-regions

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ABSTRACT

Sustainability is one of the key global economic priorities as all countries face the critical climate change challenge. In this paper we examine it in terms of Eco-Innovation (EI) from the perspective of the "business innovation modes" and study it in relation to macro-regional geographies in Europe. We analyse the small and medium-sized enterprise (SME) EI performance based on the adoption of a few archetypical business innovation modes, namely, the science and technology-based mode (STI), the learning-by-doing, by-using and by-interacting modes (DUI) or a combination of these two. These modes represent distinct bundles of practices adopted by firms based on their access to resources, skills and capabilities within and outside the firm. Therefore, this analysis diverges from most analyses focused on the impact of technology-push and demand-pull EI drivers. In this strand of literature, derived from research on innovation systems, these modes have been shown to produce a differentiated impact on innovation outputs. Our study is based on a sample of more than 15,000 business observations taken through the Eurostat Community Innovation Survey (CIS) 2014, the last European CIS survey with a section on eco-innovation. The results show different modes/practices applied in selected institutional and technological contexts (macro-regions) with varying rates of success. These findings deliver useful insights on the effectiveness of such business practices in stirring eco-innovation. In doing this, this study points out the role of the institutional and technological context on business EI practices in these macro-regions. Overall, this paper is a comprehensive study of the effectiveness of specific business innovation modes in different institutional contexts. The literature on innovation modes and innovation systems benefits by expanding its analysis from the general field of regular innovation to eco-innovation.

1. Introduction

The expansion of eco-innovation is one of the key global economic priorities as all nations face the critical climate change challenge. The United Nations Sustainable Development Goals, the Paris climate Agreement 2016 and the various COP26-29 in Glasgow, Sharm-el-Sheikh, Dubai, and Baku as well as the recent UN (2024) report on "World economic situation and prospects for 2024" promote commitments and actions from all countries and their communities and economies. Among the clear examples of actions put in place by nations can be found the Horizon-Europe framework that devotes huge financial resources to respond to climate challenges (European Commission, 2022), and the approval of the EU 2022/2464 "Corporate Sustainability Reporting Directive" (CSRD) that expands the reporting obligation of large firms in relation to supply chain-related ESG aspects (Chen and Dagestani, 2023). Therefore, scholarly research is currently very active in the field of eco-innovation (EI) (Przychodzen and Przychodzen, 2015; Huang et al., 2016; Xavier et al., 2017; Demirel and Kesidou, 2019; Cornejo-Camanares et al., 2021; Chistov et al., 2021; Prokop et al., 2022; De Marchi et al., 2022, Yang et al., 2024; among others).

In this paper, we contribute to the literature on EI taken as "an innovation with environmental benefits … that can be the primary objective of innovation or the by-product of other objectives … and that can occur during the production of a good or a service, or during its consumption or use by the end-users of a product" (EU-JRC, 2014; section 13). In particular, we investigate Eco-innovation from the perspective of "business innovation modes", which are archetypical business practices associated with bundles of factors that firms adopt to innovate. This refers to an important sub-strand of the literature on innovation systems that is grounded in the seminal work of Lundvall and associates (Jensen et al., 2007) over the past fifteen years (Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde-Heras, 2016; Thoma, 2017;

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Lee and Miozzo, 2019; Doloreux and Shearmur, 2022; Parrilli et al., 2023). In relation to their geographical ascription, some of these studies have contributed to the identification of regional context specificities. The study of Parrilli and Alcalde-Heras (2016) on the Basque regional specificities is compared and differentiated from the context specificities of Norwegian firms (Fitjar and Rodriguez-Pose, 2013). The specificities of rural and peripheral regions vis-a-vis urban agglomerations has instead been studied by Doloreux and Shearmur (2022). These studies imply the context specificity of business innovation modes that impact on innovation outputs. Such studies open new opportunities for further study that give way to the current research paper on eco-innovation.

This discussion shows gaps and opens new research questions. Firstly, the hypothesised context specificity of “business innovation modes” leads to query the way large European macro-regions, characterised by their institutional and technological patterns (Hollanders et al., 2021; Hervas et al., 2021), perform in terms of innovation outputs. Secondly, within the sub-strand of “business innovation modes” -within the literature on innovation systems-there is a gap in relation to the study of eco-innovation that has been only preliminarily covered by scholars (Prokop et al., 2022; Sedita et al., 2022). This opens the prospect of researching the impact of these “business innovation modes” on EI, particularly product and process EI. Thirdly, the literature on EI focuses its attention on individual technology-push and demand-pull factors (Huang et al., 2016; Horbach, 2016; Demirel and Kesidou, 2019; Stojcic, 2021; De Marchi et al., 2022; Carfora et al., 2022; Passaro et al., 2023). Instead, in this study the focus is on the typical practices that different types of firms adopt. This leads to a new research question about the effectiveness of these business practices. Finally, we focus on the case of small and medium-sized enterprises (SME), which represent 95%–99% of the firms and 50%–60% of employment and 30%–50% of turnover (FBS, 2022), and their EI performance (Klewitz and Hansen, 2014; Cornejo-Camanares et al., 2021) to identify the specific “business innovation modes” that the SMEs adopt and their effectiveness in relation to EI.

A selection of European countries participated to the 2014 Eurostat Community Innovation Survey (CIS), which is the only EUROSTAT-CIS survey that included a specific section (13) on eco-innovations. A smaller group of countries filled in this specific section of the CIS2014. Therefore, we only have Germany in representation of the north-western European economies, Portugal and Greece for southern European economies, Latvia, Estonia, Lithuania for the Baltic countries and Slovakia, Czech Republic, Croatia, Bulgaria and Romania for central and eastern European economies (CEECs).

In our model, the STI and DUI innovation modes represent the independent variables that are analysed to interpret the Eco-Innovation performance of small firms. EI is the output variable that is retrieved from the CIS questions 13.1 where product innovation (i.e. eco-innovations for end-users) and process innovations (i.e. eco-innovations within the firm) are identified through a set of indicators that add “breadth” to the analysis. With this study, we aim to deliver significant outputs for the strand of literature on Eco-Innovation with a focus on a) the probability that the archetypical “business innovation modes” generate product and process EI, b) the impact of these innovation modes on a “breadth” of EI outputs and, c) their nuances in relation to the selected institutional contexts (i.e. macro-regions).

The next section is about the recent scholarly contributions on EI and the theoretical framework that refers to the business innovation modes, in the context of a range of European macro-regions found at different stages of development. Section three is about the methodological approach, the ATT technique and the analytical strategy. In section four and five the empirical evidence, the discussion, the conclusions and policy implications are presented.

2. Eco-innovation and business innovation modes

2.1. Eco-innovation and its drivers

According to Rennings (2000), eco-innovations have unique characteristics that distinguish them from other innovations. These features include a positive environmental impact, significant influence on policy making, and the "double externality" issue, which refers to positive externalities associated with EI in both the phases of development and application. As a result, both competitors and society may benefit from the value created through eco-innovations.

Since 2010, several contributions have been produced on Eco-innovation. Most of them clarified critical factors of EI. In her work, De Marchi (2012) clarified the importance of strategic science and technology-based drivers such as R&D. This work stresses that EI relies on cooperation with universities, knowledge-intensive business services and suppliers to a higher extent than for general innovative firms. Orlando et al. (2022) emphasised the importance of R&D investment for EI and found evidence on the strategic role of public R&D for radical EI, based on the higher capacity of public actors to take risks and invest resources. Complementarily, Chistov et al. (2021) remarked the importance of “open innovation”, R&D collaboration and external knowledge for eco-innovation insofar as Ghisetti et al. (2015) who also stressed the role of open innovation and absorptive capacity for a wider knowledge sourcing (i.e. breadth and depth) and adoption. In their view, these are critical aspects of a green-oriented innovation system that promotes the effective production of EI. s.

Other scholars stressed the importance of demand-driven factors such as the request of products that respond to environmental sustainability concerns and enhance the producers’ reputation (Stojcic, 2021). Demirel and Kesidou (2019) emphasised the importance of specific sustainability-oriented capabilities focused on enhancing the firm’s voluntary self-regulation and environmentally driven R&D, although particularly underlined the importance of “green market sensing” as a way to capture and address the green consumption needs of the customers and end-users. Kammerer (2009) emphasised the role of customer-driven eco-innovation both for private benefits (such as cost savings on energy costs for private customers), and public benefits (such as greener and less polluted environments). Huang et al. (2016) stressed the importance of customer pressure for R&D investment and collaborations towards green innovation, while De Marchi et al. (2022) indicated that customers are an important source of EI especially when combined with cooperation with other sources of knowledge (e.g. suppliers).

A third strategic factor is government policy and regulations that are imposed on businesses and communities to reduce emissions and promote environmentally friendly practices. Different empirical studies found that government regulations support the production of EIs in the case of Germany (Horbach et al., 2013), Spain (Cornejo-Camanares et al., 2021), China (Huang et al., 2016), and eastern Europe (Stojcic, 2021). Leitner (2018) supported this view with special emphasis on the business expectation of tougher future regulations. Stojcic (2021) emphasised the prospective impact of government intervention by means of regulation as well as taxation, subsidies and public procurement, particularly in the context of “production-driven economies”. Yet, other studies identify government regulation as a barrier to eco-innovation due to the bureaucracy required to access special incentives; this may act as a deterrent towards (SME) businesses (Carfora et al., 2022). Rennings and Rammer (2011) focused on the impact of environmental regulation on firm performance and found that it depends on the type of EI (e.g. more positive for sustainable mobility and less for natural resource management). More specifically, Huang et al. (2016) studied a sample of Chinese firms and found that regulation matters in a more conservative form than customer-driven pressure; the first supports EI and the related performance, while the second pushes “blue ocean” internal and network-based R&D. In China again, Yang et al. (2024) found that government regulation moderates entrepreneurial intentions and behaviours in green agricultural production. Demirel and Kesidou (2019) investigated the impact of regulation in the United Kingdom and found that "voluntary self-regulation" (e.g. adopting a corporate social responsibility approach) matters for EI as it enhances the organisation's capabilities to exploit the opportunities offered by the increasing regulatory pressure.

A fourth relevant strand of research focuses on the direct impact of EI on economic performance. Marín-Vinuesa et al. (2020) studied its impact in the Spanish context and verified a positive correlation between the production of EI and the economic growth of businesses. Similarly, the study of Przychodzen and Przychodzen (2015) on Polish firms verified this impact where eco-innovators produce higher returns on assets and equity. They also discover that, inversely, the access to finance and the size of the firm helps them reduce risk and become more eco-innovative. Carfora et al. (2022) showed the importance of eco-innovations as an intermediate objective once (SME) businesses target higher economic performance.

Recent contributions focus on advancing research on environmental innovation theory. For instance, the new emphasis on the role of Corporate Social Responsibility (CSR), which is expected to be directly connected to EI performance. Whereas some recent studies confirm this hypothesis depending on the types of firms considered, i.e. more in the case of highly polluting and state-owned enterprises (Hao et al., 2023), other studies show that it has an important impact only once it is moderated by intermediate variables such as environmental strategy and green innovation (Kraus et al., 2020). This is also studied by Horbach et al. (2022) who found that family-owned firms were more sensitive to CSR practices for EI than non-family-owned firms.

Horbach et al. (2022) focused on different theoretical perspectives (i.e. stakeholder theory, resource-based view and institutional theory) to widen their analysis of the relevant drivers of eco-innovation. This led to investigations that found the determinants of "greenness" through a broader geographical (cross-section) analysis in which "forced greenness" (i.e. regulation-driven) is proved impactful, whilst also innovation-led business prospects tend to produce higher impact on eco-innovation (see also Stojcic, 2021). This is not always confirmed as in a simultaneous study on central and eastern European countries, where the environmental behaviour of firms is not found consistently correlated with significant product EI, but where attention to process EI (i.e. energy and water management) generate an important impact on product EI, especially in lagging countries (Prokop et al., 2022).

These results seem to stress the importance of investigating the institutional embeddedness of EI. Some scholars go beyond the standard approach to regulation for EI and emphasise the importance of institutions as a moderating factor. In particular, Boutry and Nadel (2021) stress the relevance of informal institutions, transaction costs and institutional pressures or the role of environmental legitimacy. Their research approach connects with Di Maggio and Powell's (1983) "institutional isomorphism", which highlights the behavioural homogenisation processes of firms in the same sector resulting from coercive, normative and mimetic mechanisms (Idem: 136). The consideration of institutional isomorphism highlights the potential for a macro-region type of analysis, which becomes central across the original contributions of this paper (see subsection 2.3).

2.2. Eco-innovation drivers and barriers for SMEs

One key area of research on EI refers to SMEs. This is because SMEs represent 99.8% of the firms in the EU-27 in 2021 (FBS, 2022), and a significant component of employment (64% or 83 million people) and value added (52%) (FBS, 2022). This means that their engagement with EI is essential if the commitment of policy makers and countries is to be effective. If large firms implement corporate social responsibility practices within their premises, but do not bother to check their implementation along their supply chains -where SMEs are usually positioned-, the capacity of the economy to execute such commitment falls short, while scientific and political discussions on environmental sustainability remain empty words.[1]

A few scholars identified this priority and focused their contributions on the specific role of SMEs. Pacheco et al. (2017), Del Rio et al. (2017) and Marin et al. (2015) studied the approach taken by SMEs in relation to EI and found it extremely heterogeneous. Some firms are keen in undertaking environmentally friendly practices and produce eco-innovations, while others are less sensitive and committed to such targets. This is often related to the industrial sector SMEs belong to as new technologies and advanced industries tend to incorporate CSR practices and environmentally friendly practices more thoroughly (Triguero et al., 2013; Klewitz and Hansen, 2014). It is also the case of SMEs that are integrated in global value chains, thus committed to implement ISO14001 and SA8000 certified practices, which can help them to remain within the most relevant tiers of supply of leading multinational companies. Complementarily, on a sample of Spanish SMEs, Cornejo-Camanares et al. (2021) found that compliance with regulation is the main driver for non-technological EIs (commercial and organisational).

Simultaneously to the research on key aspects of the SME capacity to eco-innovate, other scholars focused on critical factors that may restrain SME capacity. According to Hjelm and Lindahl (2016), SMEs face challenges when it comes to addressing the double externality of EI, as they often lack the necessary resources to eco-innovate. To overcome these limitations, SMEs can benefit from linkages with external actors (e.g. in terms of knowledge and networking) to access resources that complement their current skills and capabilities. This aspect of networking is also stressed by Carfora et al. (2022) who show how networking becomes a determinant of eco-innovation across SMEs. This occurs with the difficult access to finance that may prevent SMEs from arranging environmentally friendly processes to produce eco-innovation or simply be certified as environmentally friendly producers within their respective supply chain (Cecere and Mazzanti, 2012). Other scholars instead assessed the capacity of SMEs to produce EI that have an impact on their economic performance. In the Italian industrial district context, Daddi et al. (2012) and in Egypt, Mady et al. (2023) found a positive correlation between EI and performance, which justifies the effort of governments to support the wider adoption of environmental standards by SMEs.

2.3. The regional and institutional dimension of eco-innovation

Until these days, most studies on eco-innovation have taken either a country specific approach (Demirel and Kesidou, 2019; Marin et al., 2015; Przychodzen and Przychodzen, 2015; Huang et al., 2016; Cecere and Mazzanti, 2012; Cornejo-Camenares et al., 2021; Mady et al., 2023) or a cross-country approach focused on larger geographies such as the European space (Triguero et al., 2013; Del Rio et al., 2017; Stojcic, 2021; Prokop et al., 2022; Sedita et al., 2022; Parrilli et al., 2023). However, a limited number of studies have tried to identify typologies of countries/regions that have different approaches to eco-innovation based on specificities such as the importance of regulation, subsidies and external R&D for eastern European countries (Horbach, 2016; Stojcic, 2021); the centrality of intermediaries and their support to transitions across regions (Kanda et al., 2019); or their environmental behaviour through the management of critical inputs, such as water and energy (Prokop et al., 2022). These studies point out the "institutional isomorphism" (Di

[1] The role of the European Observatory for SMEs to assess this effort is important. The latest report focuses on SMEs and environmental sustainability. https://single-market-economy.ec.europa.eu/smes/sme-strategy/sme-performance-review_en#paragraph_885. The above mentioned new EU Corporate Sustainability Reporting Directive 2022 is structured to address this issue.

Maggio and Powell, 1983) that homogenise the firms' behaviour within certain business practices that fit different macro-regions' innovation pathways (Boutry and Nadel, 2021; Sedita et al., 2022; Sobczak et al., 2022).

This effort is important because between innovation and eco-innovation there are significant differences. For instance, interesting patterns can be observed such as the very good attainment of eastern European economies in relation to reducing emissions significantly over the past twenty years (EU-JRC, 2014). The European geography is heterogeneous and shows institutional, and technological/economic variations across countries that are likely to affect the capacity of their SMEs to produce EI (Cooke, 2011; Boutry and Nadel, 2021). This is what we highlight through this specific study.

North-western European countries have strengthened their institutional approach by taking a longstanding commitment to environmentally friendly practices both to conserve their environmental resources, i.e., the Scandinavian countries (Cooke, 2011), and to use effectively their limited natural resources to supply their large population (e.g. Germany and France). Southern European countries have pursued catching-up with "standardisation" processes monitored by European Union institutions (Beltran-Esteve and Picazo-Tadeo, 2017; Hervas et al., 2021). This applies also to their environmental practices that have been implemented in a rather patchy form. This is the case of the use of waste disposal infrastructures and recycling practices that are implemented inconsistently across regions within the same country, e.g. Italy (Marin et al., 2015). Eastern European countries are on a catching-up trajectory through their connection with supply chains dominated by the leading European countries (e.g. the automotive industry in Czech Republic, Slovakia, Hungary, Romania and Bulgaria; see Blazek et al., 2018). For this reason, their response on EI is more consistent than in the previous group (EU-JRC, 2014). Prokop et al. (2022) found differences in relation to the environmental behaviour of lagging vs more advanced economies in the CEEC macro-region, whilst Horbach (2016) showed that in this context EI is linked to the application of regulation and subsidies, particularly for applied R&D and technology transfer. The Baltic countries benefit from their proximity to the Scandinavian region and show higher levels of innovation (Prokop et al., 2022; Sedita et al., 2022). For instance, Estonia, and to a smaller extent Lithuania, moved to intense investments in R&D to promote EI within their industries (Melece and Hazner, 2017; Hollanders, 2021). Overall, this heterogeneity across macro-regions shows Di Maggio and Powell's institutional "isomorphism" (Boutry and Nadel, 2021)within the European space. This justifies a detailed study of the way these groups of countries and their SMEs produce not only innovations (Hollanders, 2021; Hervas et al., 2021) but also EI (Stojcic, 2021; Prokop et al., 2022; Sobczak et al., 2022; Sedita et al., 2022; Parrilli et al., 2023).

This typology of European macro-regions is somehow different from those developed from other authors in relation to eco-innovation (Horbach, 2016; Kanda et al., 2019; Stojcic, 2021; Sobczak et al., 2022; Prokop et al., 2022; Sedita et al., 2022). This is based on our specific objective, which is focused on understanding the archetypical business practices (i.e. STI and DUI innovation modes) adopted by small businesses to produce eco-innovation. These "business innovation modes" represent a structurally different approach vis-a-vis others that analyse types of drivers (e.g. technology-push and demand-pull as for instance in Kesidou and Demirel, 2012, 2019; or product, process and systemic-type models as in Xavier et al., 2017). In this case, the analysis is based on the logic and practices (i.e. divergent bundles of drivers) that SME entrepreneurs and business teams take to perform EI and attain economic growth. These modes are also representative (at the regional level) of continuously changing institutional and techno-economic landscapes across Europe and beyond (Parrilli et al., 2020; Hervas et al., 2021; Boutry and Nadel, 2021).

2.4. The business innovation mode approach: an original interpretation key for EI

Following on from this discussion, in this study we take a specific approach to eco-innovation. It is called the "business innovation mode" approach and is critical to understand the archetypical practices (i.e. bundle of resources, skills and capabilities) that firms use to pursue their eco-innovation objectives. As mentioned above, this approach is different from other approaches that identify models based on more specific type of drivers (i.e. technology-push and demand-pull, Kesidou and Demirel, 2012, 2019; or product-based, process-based and systemic-based, as in Xavier et al., 2017). Instead, this approach entails typical practices (bundles of activities) that firms implement within their premises. This is novel in that it is not prescriptive, but rather based on current practices applied by firms. Roscoe et al. (2016) made a similar attempt in relation to the way supply chain management is organised for EI, though in our case, firm practices are considered beyond the supply chain to entail the broader eco-innovation system. This approach takes the form of two very different modes/practices one of which is based on science and technology drivers (STI mode) within the firm (R&D expenditure) and in inter-firm relations (e.g. collaboration with universities and public research centres). The other (DUI) is based on across-the-board personnel collaborations within the firm (across different departments) and outside the firm (collaborations with suppliers and buyers). In specific cases, firms can use the combined mode STI + DUI, which tends to generate higher innovation outcomes (Jensen et al., 2007; Nunes and Lópes, 2015; Parrilli and Alcalde-Heras, 2016; Thoma, 2017; Parrilli et al., 2020; Doloreux and Shearmur, 2022).

In the case of SMEs, the business modes/practices adopted to develop innovations are biased towards the use of the DUI mode because it is cheaper (Thoma, 2017; Parrilli and Radicic, 2021). Notwithstanding, it is not always effective as most SMEs are expected to adopt it while only a minority of them are effective in generating substantial innovations (Hervas et al., 2021). Usually, the STI mode is more effective for radical innovation, although it is applied by a minority of firms and SMEs (Ibid.). This raises questions and opportunities for scientific research to understand and promote the best and most effective innovation mode. This whole discussion extends to the boundaries of EI as this is also affected by the innovation modes undertaken by SMEs.

Marzucchi and Montresor (2017) and Parrilli et al. (2023) have taken this approach to the EI field. The former scholars studied the importance of these modes in relation to internal and external activities focused on producing EIs. They found out that there is a clear difference and that, whether the STI mode and its drivers are usually effective within the firm, the DUI mode and its drivers are more effective in external EI collaborations. Moreover, they found that green products benefit more from STI drivers, while efficiency related EIs (process EIs) benefit more from DUI drivers (Marzucchi and Montresor, 2017). These findings are supported by Parrilli et al. (2023) that additionally studied the impact of innovation modes on a larger set of EIs that include product, process, organisational and commercial EIs across a significant group of eastern and southern European countries.

2.5. Main argument and hypotheses

On these bases, we develop our argument that pulls together the literature on EI with the strand on "business innovation modes" and discusses these within the variegated European "institutional and technological" geography. In this study, we follow our anticipated "institutional isomorphism" approach (Di Maggio and Powell, 1983; Boutry and Nadel, 2021) that also highlights the technological and economic features that characterise some homogeneous territories within the European space (Parrilli et al., 2020; Hollanders, 2021; Hervas et al., 2021; Stojcic, 2021; Sobczak et al., 2022; Prokop et al., 2022; Sedita et al., 2022). On these bases, we expect north-western European countries to be at the forefront of development of EI as they have developed a consistent approach to the use of renewable energies and the conservation of natural resources for several decades (Cooke, 2011). It is the case of Germany and Denmark that lead the wind energy and the photovoltaic industries which already provide more than 40% of the total energy requirement (Horbach, 2016; Horbach and Jacob, 2018; Leitner, 2018). In this case, the use of the STI mode is likely to be effective as a significant proportion of firms in these countries devote significant resources to R&D expenditure, recruitment of scientists, and collaborations with universities and private research centres for the purpose of attaining a greener and more sustainable economy (Hollanders, 2021).

From previous studies (Vega-Jurado et al., 2008; Trott and Simms, 2017; Parrilli et al., 2020), we know that product and process innovation respond differently to the business innovation modes and that the stronger focus on STI drivers in western Europe is likely to generate a very strong impact on product eco-innovation. On these bases, we formulate the following hypotheses.

H1a. SME firms in north-western European countries are likely to adopt the STI mode more effectively than the DUI mode for product eco-innovations.

H1b. SME firms in north-western European countries are likely to show a stronger impact of the DUI mode on process eco-innovation.

In the case of southern European countries, the approach to EI is heterogenous and patchy as these countries are catching-up on innovation in general (Hervas et al., 2021). These countries have built their trajectory on tourism and agro-food production, while have only irregularly developed substantial industrial bases (e.g. centre-north of Italy, north of Spain) or service-oriented economies (e.g. financial industry in large cities in Spain). Although recent studies on Spain have shown the importance of both innovation modes (STI and DUI) for internal and external knowledge purposes (Marzucchi and Montresor, 2017), in these economies most firms and even more clearly the SMEs tend to adopt learning-by-doing and interactions (the DUI mode), which are not always effective. In fact, most DUI drivers such as teamwork, training and supply chain collaborations tend to be used quite intensely by SMEs due to their relatively low cost. Instead, in these contexts the resources available for investment in STI drivers are lower (Hollanders, 2021), thus the adoption of the STI mode is more limited and associated to specific high-technology industries (e.g. pharma and biotech, ITCs, aerospace) that represent a limited segment of industries in these countries.

In such contexts, the impact of STI and DUI modes on product and process EI is going to be differentiated. We expect the STI mode to be less significant than in the previous case, including for product eco-innovation. Instead, the DUI mode is expected to be relatively more impactful, though mostly for process EI. On these bases, we formulate the following hypotheses.

H2a. SME firms in Southern European countries are likely to adopt the DUI mode as effectively as the STI mode for product eco-innovation.

H2b. SME firms in Southern European countries are likely to adopt the DUI mode more effectively than the STI mode in process eco-innovation.

The case of the central and eastern European countries is similar to the case of southern European countries, although their industrial and institutional organisation is quite different. Most of these countries rely on the connection with large multinational companies based in Germany or France in the production of automotive vehicles (Blazek et al., 2018). In this case, EI is not expected to rise to the highest extent as SMEs are involved in supply chain activities where they operate under strict technical specifications (Ibid.) and certified industrial practices (e.g. ISO14001, SA2008). These practices do not require strong investment in R&D or university-industry collaborations, and instead EIs are targeted through the DUI mode and its drivers (e.g. technology transfer or collaboration with buyers and service providers for ISO-certified processes, Horbach, 2016; Stojcic, 2021; Prokop et al., 2022) that face the same issues discussed in the case of southern European countries, and add those of a social economy grown out of the former Soviet Union influence (Sedita et al., 2022).

As for the former group of countries, STI and DUI drivers are not expected to differ much in terms of their impact on product EI, whilst the DUI mode is expected to generate a significantly higher impact on process eco-innovation. On these bases, we formulate the following hypotheses.

H3a. SME firms in central and eastern European countries are likely to adopt the DUI mode as effectively as the STI mode for product eco-innovation.

H3b. SME firms in central and eastern European countries are likely to adopt the DUI mode more effectively than the STI mode for process eco-innovation.

The case of Baltic economies is taken aside as these are former Soviet Union countries, but they are also in close proximity with the economically and technologically most advanced northern European economies (i.e. Scandinavian countries), and strongly connected with the NATO that they joined 20 years ago. These peculiarities raised the prospect of benefiting from critical technology transfer. The case of Estonia is outstanding as this country invests significant amounts of resources in R&D expenditure (1.80% which is higher than 1.71% of the UK, see World Bank, 2022; Melece and Hazner, 2017). With reference to their unique institutional environment and historic, cultural legacy (Sedita et al., 2022), this led to the creation of skills and capabilities across a specialised workforce and helped them implement the STI mode and drivers in a more efficient manner. This generated a higher absorptive capacity which gave room to the firms to invest in R&D and university-industry collaborations and extract significant impact on innovation outputs (Cohen and Levinthal, 1990).

In this context, a stronger impact of STI drivers is expected, particularly in relation to product eco-innovation, whilst for process eco-innovation a stronger impact is expected from the DUI mode due to the non-technological nature of process innovation (Prokop et al., 2022). As a consequence, the Baltic countries are expected to behave rather similarly to the most advanced north-western economies. Based on this discussion, we formulate the following hypotheses.

H4a. SME firms in the Baltic countries are likely to adopt the STI mode more effectively than the DUI mode for the creation of product eco-innovation.

H4b. SME firms in the Baltic countries are likely to adopt the DUI mode more effectively than the STI mode for the creation of process eco-innovation.

3. Methodology

3.1. Sample and data

The data used in our analysis stem from the cross-sectional Community Innovation Survey 2014 (CIS), micro level, cross-sectional database for 2012–2014. The questionnaire is harmonised for all EU Member States in accordance with methodological recommendations introduced in the Oslo Innovation Manual, which combine random sampling with a comprehensive firm level survey (OECD, 2005; Prokop et al., 2019). Advantages and limitations of the CIS have been thoroughly explained in the literature (Parrilli et al., 2020). It is a widely used dataset with information about firm innovation activities, and particularly eco-innovation. Data on EI are not an integral part of every edition of CIS; the CIS2014 is the latest version of questionnaire that include questions on a firm's EI activities. Therefore, it is the questions incorporated in the CIS2014 questionnaire that enable us to measure the number of environmental benefits/eco-innovations.

Previous studies utilise CIS data to measure EI, but they only focus on whether the firms adopt any type of EI (e.g. Parrilli et al., 2023). In this case, we contribute to the literature by moving beyond the simple introduction of EI and for the first time in the literature we also measure the impact of STI and DUI innovation modes on the breadth of EI (i.e. a wide range of EI).

3.2. Dependent (outcome) variables

The dependent variable, EI in a broad sense, is expressed as an innovation that generates certain environmental benefits (see Section 13 of CIS, 2014). However, our focus is on the range of EIs (i.e. breadth) rather than mere introduction of EI ("yes" or "not"). We start with *Total eco-innovation*, which is a cumulative index of ten different environmental benefits (this definition is also used in Vasileiou et al., 2022). This variable is created by summing up to ten dummy variables, contingent on the number of affirmative responses provided by respondents regarding each benefit of product and process eco-innovations. The second dependent variable is *Process eco-innovation,* which is a cumulative index of six different environmental benefits related to process EIs (Vasileiou et al., 2022). This variable is constructed by combining up to six dummy variables, based on the respondent's number of positive answers regarding each benefit of process EIs (see Table 1). The third dependent variable is *Product eco-innovation,* which is a cumulative index of four different environmental benefits related to product EIs (similar to Vasileiou et al., 2022). This variable is created by adding up to four dummy variables, depending on the number of confirmatory responses provided by respondents regarding each type of benefit of product EIs.

3.3. Treatment variables

The literature on eco-innovation consider collaboration as an essential tool for innovation development (Wagner, 2008; Mazzanti and Zoboli, 2009; Chistov et al., 2021). Business innovation modes (STI and DUI) are classified according to Jensen et al. (2007) and includes firms' internal activities connected with STI or DUI innovation modes alongside different types of collaboration (Parrilli et al., 2020, 2023). Distinct from analyses that quantified STI and DUI based on various forms of collaboration (Chen and Dagestani, 2023; Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde-Heras, 2016; Haus-Reve et al., 2019), the main advantage of our analysis is based on taking into account also the internal activities of companies related to these innovation modes (Parrilli et al., 2020; Parrilli and Radicic, 2021). It is considered that a firm engages in the STI mode if it either undertakes (internal and/or external) R&D activities or cooperates with higher education institutions and government research centres, while the DUI mode includes in-house activities (i.e. in-company training, design, and market introduction of innovations) and cooperation with suppliers, customers, and competitors. Table 1 elaborates the protocol for the creation of the treatment variables.

Across the selected macro-regions, particularly the north-western European economies, we only have data for Germany, and that is why we prefer referring directly to this country rather than to the wider group of countries that did not submit their response to the EU -CIS survey on Eco-innovation (Section 13). German SMEs are peculiar in terms of business modes as the sample data record only one firm that engaged in the DUI mode alone.

3.4. Control variables

As far as control variables are concerned, we control for the regulatory and policy side, demand-side and firm-specific factors. These are well-embedded in the eco-innovation literature (Horbach et al., 2012; Del Rio et al., 2017; Greco et al., 2020; Chistov et al., 2021). On the policy-side, variables that are centred around environmental regulations, taxes and grants are included in the models. Regulation is often perceived in the literature as a fundamental factor for the development of eco-innovation within firms (Del Rio et al., 2017; Chistov et al., 2021). Firms adopt EI as a response to the demand for green products and corporate image (Kammerer, 2009; Chassagnon and Haned, 2015). To control for this, the binary variable, which measure whether demand and reputation is of high or medium importance to engage in eco-innovation, has been considered. Firm-specific factors refer to firms' characteristics such as firms' exports and belonging to a business group. The sectoral effect is captured by the set of dummies calculated at NACE 2-digit sectors classified according to technological intensity (classification shown in Table 1). Firms that belong to a group and sell their products and services in foreign markets are more likely to adopt EI than non-group members and non-exporters (Ghisetti, 2017; Marzucchi and Montresor, 2017; Greco et al., 2020). Facing tougher competition in international markets pushes firm to innovate. As for a group membership, the possibility to gain access to external knowledge (to the group) reinforces the absorptive capacity of the principal firms, which induces to higher levels of eco-innovation.

3.5. Empirical strategy

STI and DUI innovation modes are regarded as endogenous variables. Namely, internal and external R&D activities are considered endogenous in the knowledge production function (Duso et al., 2014). Moreover, there is a potential simultaneous causal relationship between cooperation for innovation and innovation performance (Vivas and Barge-Gil, 2015; Pippel and Seefeld, 2016; Haus-Reve et al., 2019; Parrilli and Radicic, 2021).

Our empirical strategy addresses an issue of endogeneity by estimating treatment effects, in particular the average treatment effects on the treated (ATT). Furthermore, to account for the possibility that firms are subject to two treatments (STI and DUI modes), we estimate treatment effects in the multiple treatment contexts introduced by Lechner (2001). We have M+1 treatments, whereby treatment = 0 denotes firms that do neither engage in STI nor DUI; treatment = 1 denotes engagement in the STI mode only; treatment = 2 refers to engagement in the DUI mode alone; and treatment = 3 refers to engagement in both innovation modes altogether. The average treatment effect on the treated (ATT) effect is calculated as:

$$ATT = E(T = m) - E\left(Y^l \middle| T = m\right) \quad (1)$$

Where m denotes the treatment level, T represents the comparison group (the treatment level to which m is compared, Czarnitzki et al., 2007), and Y^m and Y^l denote outcomes at treatment levels m and l respectively. Equation (1) is estimated via the inverse probability of treatment weighing the regression adjustment (IPWRA) estimator.

The first step is the estimation of the propensity scores. Given the multilevel treatment context, a multinomial logit model is estimated to include all four treatment levels: neither STI nor DUI; only DUI; only STI; and both.[2] Firms within each treatment level are matched on estimated propensity scores. Given that the dependent (outcome) variables are categorical, in the second step the OLS models are estimated, in which the inverse of the estimated propensity scores are used as weights on covariates (matching variables) and the treatment binary variables. In the final step, from each of logit regressions, the ATT effects are computed as the difference in the weighted averages of the predicted outcomes (Wooldridge, 2010). This three-step approach provides consistent treatment effects given the underlying assumption of the independence of the treatment from the predicted outcomes in the final step. Appropriate Huber/White/sandwich standard errors are estimated

[2] Results from multinomial logit models are not reported but are available upon request.

Table 1
Descriptive statistics.

Variables	Variable description	Northern Europe (Germany)	Southern Europe	Central and Eastern Europe	Baltic
		Percentage	Percentage	Percentage	Percentage
Treatment	A categorical variable defined as:				
	Neither STI nor DUI innovation modes (treatment = 0)	68.16	24.06	33.36	20.74
	only the STI mode (treatment = 1)	20.32	11.01	11.26	13.22
	only the DUI mode (treatment = 2)	0.02	26.71	29.91	27.75
	the combined mode STI + DUI (treatment = 3)	11.50	38.21	25.47	38.29
Outcome variables					
		Mean (st. deviation)	**Mean (st. deviation)**	**Mean (st. deviation)**	**Mean (st. deviation)**
Product eco-innovation	Number of a product (good or service). innovations with any of the following environmental benefits obtained during the consumption or use of a good or service by the end user: Reduced energy use or CO2 'footprint'; reduced air, water, noise or soil pollution; facilitated recycling of product after use or extended product life through longer-lasting, more durable products.	0.758 (1.229)	0.936 (1.114)	0.429 (0.977)	0.557 (1.107)
Process eco-innovation	Number of a process innovations with any of the following environmental benefits within firms: Reduced material or water use per unit of output; Reduced energy use or CO2 'footprint' (reduce total CO2 production); Reduced air, water, noise or soil pollution; Replaced a share of materials with less polluting or hazardous substitutes; Replaced a share of fossil energy with renewable energy sources; Recycled waste, water, or materials for own use or sale;	1.502 (1.749)	1.577 (0.936)	0.691 (1.363)	0.978 (1.455)
Matching (control) variables					
Exports	DV = 1 if a firm sold goods and/or services to countries other than the home country in the period 2012–2014; zero otherwise	0.484 (0.499)	0.725 (0.447)	0.622 (0.485)	0.767 (0.423)
Group	DV = 1 if a firm belong to enterprise group; zero otherwise	0.2605 (0.439)	0.263 (0.440)	0.339 (0.473)	0.422 (0.494)
High_tech	DV = 1 if a firm belongs to a high-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise.	0.063 (0.242)	0.0123 (0.110)	0.0201 (0.1404)	0 (0)
Medium_high_tech	DV = 1 if a firm belongs to a medium high-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise.	0.099 (0.299)	0.075 (0.264)	0.083 (0.276)	0.0901 (0.286)
Medium_ low	DV = 1 if a firm belongs to a medium low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise.	0.184 (0.389)	0.213 (0.409)	0.172 (0.377)	0.151 (0.358)
Low tech	DV = 1 if a firm belongs to a low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.172 (0.377)	0.254 (0.436)	0.241 (0.428)	0.206 (0.404)
Knowledge intensive services (KIS)	DV = 1 if a firm belongs to a knowledge-intensive service (KIS) sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.259 (0.438)	0.187 (0.389)	0.189 (0.392)	0.256 (0.436)
Less knowledge intensive services (KIS)	DV = 1 if a firm belongs to a less knowledge-intensive service (KIS) sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.137 (0.344)	0.207 (0.405)	0.233 (0.423)	0.198 (0.399)
Environmental regulation	DV = 1 if existing environmental regulations is high or medium important in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.254 (0.436)	0.455 (0.498)	0.212 (0.408)	0.342 (0.474)
Environmental taxes	DV = 1 if existing environmental taxes/charges/fees is high or medium important in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.1403 (0.347)	0.347 (0.476)	0.172 (0.377)	0.288 (0.453)
Environmental grants	DV = 1 if government grants, subsidies or other financial incentives for environmental innovations is high or medium important in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.108 (0.311)	0.191 (0.393)	0.113 (0.317)	0.182 (0.386)
Environmental demand	DV = 1 if current or expected market demand for environmental innovations is high or medium important in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.122 (0.328)	0.293 (0.455)	0.163 (0.369)	0.244 (0.429)
Reputation	DV-1 if improving firm's reputation is high or medium important in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.198 (0.399)	0.487 (499)	0.237 (0.425)	0.394 (0.489)

(Emsley et al., 2008).

4. Empirical results and discussion

4.1. Descriptive statistics

Descriptive statistics for the selected variables are available in Table 1. SMEs in southern Europe record the largest average proportion of both product and process EIs, with almost 1 and more than 1.5 innovations per firm respectively. The average number of process EIs in SMEs in Germany is the same as in Southern Europe (1.5 per firm), while the average proportion of product EIs is slightly lower, which might be explained with the stronger focus on expensive radical innovation. On average, SMEs in the Baltic produce more than 0.5 product EI per firm and almost one process EI per firm. The lowest number of EIs per SME is recorded in central and eastern Europe (see Table 1). These results complement previous findings which argue that less competitive countries (in eastern and southern Europe) produce more process innovation than the most competitive countries (Hervas et al., 2021). However, when it comes to EI and particularly the breadth of EIs, SMEs in southern Europe overcome Germany in case of both, product and process EIs. Simultaneously, SMEs in central and eastern Europe seem to be less diversified in terms of EIs than SMEs in the rest of the continent.

4.2. Econometric results

In the case of southern European countries (Table 2), the probability to produce both product and process EIs does respond to the combined STI + DUI and product innovation also to the DUI mode, while the STI mode is linked negatively for product innovation implying an extremely inefficient use of the STI mode in this macro-region. In relation to the type of firms, in both cases (total firms and SMEs) the DUI mode is always more important than the STI mode, while the combined STI&DUI mode is more effective than the individual modes. These same results apply to the "breadth of eco-innovations", i.e. the capacity of these modes to promote an increasing range of EIs. In this case, the DUI mode is more effective in generating a larger range of EIs for both product and process EI. This evidence generally supports our hypothesis H2a partially (as the STI is not significantly related to product eco-innovation) and H2b in full. These results are expected, while perhaps the large ineffectiveness of the STI mode in the case of product EI deserves attention as it shows the incapacity to make this mode and its drivers (e.g. R&D, cooperation with universities) work effectively, thus the important policy steps that need to be taken to change this laggard pattern.

In the case of central and eastern European countries (Table 3), the probability to produce process EIs is mostly associated with the combined STI&DUI mode and the individual DUI mode, which matters significantly more than the STI drivers. The same happens for product EIs, although in this case there is no predominant role for DUI drivers. In relation to the breadth of EI, the above results are maintained and similar between total firms and SMEs. These findings are very similar to those found in southern European economies. The combined STI&DUI mode is the most effective with DUI drivers that matter more than STI drivers for process EI, while no predominance can be shown in the case of product EI, neither in the case of all firms nor across the SMEs. This evidence supports our hypotheses H3a partially as the STI mode alone is not promoting product innovation (it does when combined with the DUI mode), while H3b is fully supported.

In relation to the Baltic countries (Table 4), the probability to produce process EIs does not rely on the application of any innovation mode, while the probability to produce product EI is associated with the application of STI drivers and the combined mode STI&DUI. This outcome is different from the previous cases as we observe the capacity of businesses to make the STI drivers work effectively. In relation to the breadth of EI, in both the case of total firms and the SMEs the combined STI&DUI mode is the most effective, although both the STI and the DUI mode individually are effective for product and process EI. This is not replicated across the SMEs for which these individual modes are less effective (while the combined mode is). Overall, there is no predominance of either mode within the combined STI&DUI mode in relation to any type of EI. These findings stress the increased role of STI drivers in the generation of EI in the Baltic countries vis-à-vis the two previous categories of countries. H4a is partially supported as the STI mode alone is significant for product innovation (alone and in combination with the DUI mode) but also the DUI mode alone it is and there is no predominance of any of the two. H4b is broadly supported as the DUI mode is significant and positive for process EI both when working alone and in combination with the STI mode.

In relation to Germany (Table 5), the sample available is large and shows the lack of firms adopting the DUI mode alone. For this reason, our analysis leaves empty the case/column of "DUI vs none" as well as the case of "Both vs DUI" and "STI vs DUI". This seems to point out that in the German case, firms focus on eco-innovation through the STI drivers (R&D). Those firms that take a proactive approach towards innovation are also likely to understand and utilise the DUI mode complementarily (STI + DUI mode). Here, we cannot produce the probability results while we can produce the table on the breadth of innovation for all firms and for SMEs.

Most information is about the use and effectiveness of the STI mode and its drivers. They are all extremely effective in both product and process EI, and in both the total number of firms and the SMEs. In product EI, the coefficient of the STI mode is higher for all firms vis-à-vis the SMEs, while in the case of process eco-innovation it is SMEs that show the highest coefficient, which confirms that preference of SMEs for process (eco)innovations (Parrilli and Radicic, 2021). Moreover, the third column shows the importance of taking a combined STI&DUI innovation mode that delivers additional output both in product and process EI in the case of all the firms. In contrast, in the case of SMEs the combined mode is more effective in product EI but not in process EI, thus highlighting the main (DUI) mode adopted by SMEs in process EI. Overall, despite the limitations of this final sample, we find evidence of a quite different approximation of firms and SMEs to EI. The STI mode becomes central and extremely effective both in isolation and in combination with the DUI mode. The combined mode is certainly the most effective mode as it was shown in other studies on EI (Parrilli et al., 2023). In Germany, no firms lock themselves within the DUI mode alone, although the latter still contributes to the overall innovation impact on EI as the effectiveness of the combined STI&DUI mode shows. Our hypothesis H1a is confirmed in relation to the strength of the STI mode, though no clear comparison can be made with the DUI mode as no firms are undertaking such a mode alone (in our relevant sample). H1b is not supported due to the lack of firms adopting the DUI mode alone.

4.3. Discussion

This study produces some theoretical contributions. In the field of EI, it introduces the perspective of "business innovation modes", which are the business practices (i.e. adoption of bundles of drivers) that firms use to produce eco-innovations (Marzucchi and Montresor, 2017; Parrilli

Table 2
Southern European countries (Portugal and Greece).

		IPWRA						
Types of innovation		STI vs none	DUI vs none	Both versus none	Both vs DUI	Both versus STI	STI vs DUI	
Number of innovations	Total	−0.125 (0.191)	0.2697** (0.1172)	0.487*** (0.1015)	0.295*** (0.1196)	0.656*** (0.1375)	−0.394*** (0.117)	All firms
	Process	−0.0126 (0.021)	0.1501** (0.0748)	0.2771 *** (0.067)	0.1571 ** (0.0735)	0.3099*** (0.0865)	−0.163** (0.074)	All firms
	Product	−0.115** (0.0594)	0.1185** (0.0578)	0.2054*** (0.0497)	0.1358** (0.0606)	0.3402*** (0.0719)	0.233*** (0.059)	All firms
						–		
	Process	−0.011 (0087)	0.135* (0077)	0.337*** (0.075)	0.198*** (0.066)	0.350*** (0.086)	−0.146** (0.075)	SMEs
	Product	−0.119* (0.066)	0.103* (0.061)	0.216*** (0.057)	0.172** (0.053)	0.378*** (0.069)	−0.222*** (0.060)	SMEs
Probability to eco-innovate	Process	0.0026 (0.0189)	0.026 (0.017)	0.025 (0.0167)	0.0005 (0.0156)	0.026 (0.0203)	−0.023 (0.017)	
	Product	0.0012 (0.0122)	0.036*** (0.102)	0.079*** (0.010)	0.288 (0.0208)	0.1125*** (0.0259)	−0.089*** (0.0214)	
No of observations:					4739			

Table 3
Central and eastern Europe (Hungary, Slovakia, Romania, Bulgaria, Croatia).

		IPWRA						
Types of innovation		STI vs none	DUI vs none	Both versus none	Both vs DUI	Both vs STI	STI vs DUI	
Number of innovations	Total	−0.0462 (0.096)	0.191** (0.0885))	0.516*** (0.091)	0.4403*** (0.1119)	0.873*** (0.1566)	−0.237*** (0.093)	All firms
	Process	−0.054 (0.062)	0.1378** (0.058)	0.298** (0.059)	0.188*** (0.075)	0.5323*** (0.115)	−0.192*** (0.063)	All firms
	Product	−0.0008 (0.0553)	0.043 (0.049)	0.209*** (0.049)	0.255*** (0.051)	0.340*** (0.074)	−0.0008 (0.0553)	All firms
	Process	−0.017 (0.087)	0.092 (0.081)	0.256*** (0.084)	0.213*** (0.067)	0.338*** (0.111)	−0.108*** (0.064)	SMEs
	Product	0.034 (0.084)	0.069 (0.080)	0.169** (0.082)	0.148*** (9.052)	0.244*** (0.087)	−0.033 (0.048)	SMEs
Probability to innovate	Process	−0.0149 (0.155)	0.0195 (0.015)	0.056*** (0.015)	0.035*** (0.0139)	0.113*** −0.034** (0.022) (0.0172)		
	Product	−0.0008 (0.0553)	0.043 (0.049)	0.209*** (0.049)	0.255*** (0.051)	0.3400*** −0.044 (0.074) (0.043)		

Table 4
Baltic countries (Lithuania, Estonia and Latvia).

			IPWRA					
Types of innovation		STI vs none	DUI vs none	Both versus none	Both vs DUI	Both versus STI	STI vs DUI	
Number of benefits	Total	0.231 (0.165)	0.502*** (0.327)	0.346*** (0.1444)	0.446*** (0.1426)	0.156 (0.1432)	−0.134 (0.093)	All firms
	Process	0.083 (0.094)	0.266*** (0.085)	0.131*** (0.020)	0.207** (0.097)	0.086 (0.0904)	−0.1427 (0.145)	All firms
	Product	0.168** (0.086)	0.234*** (0.059)	0.254*** (0.074)	0.2713*** (0.0835)	0.069 (0.713)	0.0100 (0.083)	All firms
	Process	0.042 (0.105)	0.175 (0.119)	0.278*** (0.1002)	0.223*** (0.089)	0.056 (0.094)	−0.132 (0.119)	SMEs
	Product	0.1013 (0.098)	−0.016 (0.093)	0.273*** (0.081)	0.223*** (0.078)	0.206*** (0.703)	0.053 (0.086)	SMEs
Probability to innovate	Process	−0.0321 (0.023)	0.001 (0.027)	−0.007 (0.024)	−0.0004 (0.0159)	0.025 (0.0163)	−0.033 (0.024)	
	Product	0.065** (0.289)	0.0447 (0.028)	0.103*** (0.025)	0.080*** (0.025)	0.068** (0.0313)	0.0199 (0.029)	
No of observations			1978					

Table 5
Germany.

		IPWRA			
Types of innovation		STI vs none	Both versus none	Both versus STI	
Number of benefits	Total	0.604*** (0.109)	0.759*** (0.130)	0.429*** (0.147)	All firms
	Process	0.3105*** (0.073)	0.316*** (0.091)	0.1958*** (0.098)	All firms
	Product	0.287*** (0.054)	0.2702*** (0.066)	0.226 *** (0.074)	All firms
	Process	0.366*** (0.077)	0.3112*** (0.098)	0.047 (0.108)	SMEs
	Product	0.2513*** (0.057)	0.399*** (0.077)	0.236*** (0.085)	SMEs
No of observations all firms		4896			
No of observations SMEs		3430			

et al., 2023). Thus, it is from the perspective of the firm's strategic choice (Foss et al., 2008; Nason and Wiklund, 2018), rather than from the perspective of the effectiveness of specific technology-push and demand-pull drivers as in most EI-driven studies (Demirel and Kesidou, 2019; 2019; Huang et al., 2016; Horbach, 2016; Xavier et al., 2017; Sobczak et al., 2022; De Marchi et al., 2022; among others). A second theoretical contribution refers to remarking the importance of "institutional isomorphism" (Di Maggio and Powell, 1983; Boutry and Nadel, 2021; Sedita et al., 2022), which highlights the impact of specific institutional environments for the firm generation of EI. Four European macro-regions adopt these business innovation modes in quite a varied way, which respond to their institutional, technological and economic features.

Such institutional context leads southern and central-eastern European countries to lag behind as, on the one hand (southern Europe) institutional and technological development is inconsistent and mostly linked to traditional industries (e.g. tourism, agroindustry, textiles, among others), whereas STI drivers are still marginal. In this context, firms tend to eco-innovate mostly through the application of DUI drivers (Marin et al., 2015; Parrilli et al., 2023). The same happens in central and eastern Europe, where firms are often linked to supply chain operations and guidance from multinational companies based in Germany and France (i.e. the automotive industry), and also in this case technological development occurs through the delivery of technical specifications from such leading firms rather than through the application of own R&D or university-industry collaborations (Blazek et al., 2018). Such findings align with former empirical studies on this geographical area (Stojcic, 2021; Prokop et al., 2022; Sedita et al., 2022; Parrilli et al., 2023).

In contrast, the case of the Baltic countries shows the institutional and technological transformation that has taken place in this context over the past twenty years, from joining the EU and NATO to their closer relationship with the most advanced European economies that have led to a positive imitation process (e.g. strong investments in R&D to promote economic growth; see Melece and Hazner, 2017; Sedita et al., 2022). This institutional and technological transformation have led to a more balanced approach where the STI mode plays a much more critical role to promote product EI, while also contributing in the STI&DUI combined mode for both process and product EI. Such outcome is aligned with our hypothesis and with evidence of the recent effort of Baltic countries in R&D and other research-based collaborations for eco-innovation (Prokop et al., 2022; Sobczak et al., 2022). The case of Germany is unique but also complicated to explain. Many firms seem not to adopt any innovation mode in relation to EI. As in Leitner (2018: 38), based on the same CIS 2014 data, it might be justified by widespread reliance on more general policy drivers for EI, such as the cost of fossil fuels, public financial support, and the expectation of tougher future regulations, and to a lower extent on reputation. Consequently, no firms are found in the group of DUI mode users only, while important STI elements (R&D) are found, thus confirming previous evidence (Leitner, 2018). For Germany, our analysis is limited to two modes (STI only and STI&DUI) because businesses do not conceive innovation without R&D (core STI driver). This unique case shows the huge impact that the STI mode has on both types (breadth of product and process EI), although the combined STI&DUI mode represents the most effective mode as in the other macro-regions. These results confirm the argument of an innovation leading country that adopts an STI-driven approach also in relation to product and process EI (Hollanders, 2021; Parrilli et al., 2020).

5. Conclusions

5.1. Main findings and contributions to the literature

This study contributes novel elements to the literature on eco-innovation from the critical perspective of the "business innovation modes" that represent bundles of business drivers, which are representative of the "practice" (and related "strategic choice", see Foss et al., 2008) firms adopt to produce (eco)innovations (Jensen et al., 2007; Parrilli and Alcalde-Heras, 2016). This study also adds to the literature on innovation systems and the geography of EI across selected institutional, technological and economic macro-regions (Di Maggio and Powell, 1983; Cooke, 2011; Parrilli et al., 2020; Stojcic, 2021; Boutry and Nadel, 2021; Prokop et al., 2022). In relation to the first element, this study provides evidence on the effectiveness of firm (and SME) innovation modes for both product and process EI. It also reviews the impact of such modes on a wide range of EIs (the "breadth" of EI), which had not been considered in previous studies. Overall, this study investigates a different perspective on EI through best practices and their bundles of internal and external drivers which create a new lens of interpretation of EI vis-à-vis other relevant studies which are focused on demand-pull and technology-push factors or regulation (Huang et al., 2016; Demirel and Kesidou, 2019; Horbach, 2016; Cornejo-Camanares et al., 2021; Prokop et al., 2022; Carfora et al., 2022; Passaro et al., 2023). This lens stresses the overall and sometimes unconscious practices adopted by firms rather than prescriptively assessing individual drivers.

In relation to the second research area, echoing the "institutional isomorphism" prophesied by Di Maggio and Powell (1983) and recently reconsidered by Boutry and Nadel (2021), this research focuses on four macro-regions across the European geography and identifies a typology of them where context-specific EI modes/practices are implemented and performance generated. This discussion and findings contribute to empirical studies produced in recent years, in specific countries (Spain in Marzucchi and Montresor, 2017), or specific areas (central and eastern Europe in Stojcic, 2021; Prokop et al., 2022; Sobczak et al., 2022; southern and eastern Europe in Parrilli et al., 2023, and more globally, Sedita et al., 2022).

5.2. Policy implications

In terms of policy implications, the indications vary across this set of countries. In laggard countries, the DUI mode needs to be applied more thoroughly as between 35% (southern Europe) and 45% (central-eastern Europe) of the firms do not adopt any DUI driver, which is the most effective mode in these contexts. In these macro-regions, promotion programs focused on strengthening training, teamwork, and collaboration with suppliers and buyers are essential. Instead, the firms that introduce STI drivers need to learn how to become more effective. In these initial stages, external R&D and collaboration with universities are more likely to produce higher results than high investment in internal R&D, which typically requires higher absorptive capacity. In the Baltic countries, the STI mode is substantially more effective, thus, can be strengthened by supporting those firms that have not adopted it yet (48% of the total). In this case, whilst collaboration with universities and research centres can help extend the impact of STI drivers, the adoption of internal and external R&D can also be promoted through subsidies to innovation. In the case of Germany, not much information is available on the use of DUI drivers, while the STI mode is effective, it could become more effective across SMEs that are less effective in generating a wider breadth of eco-innovations. R&D promotion could reach SMEs more extensively to support a more consistent approach to EI. In the case of SMEs, this seldom happens through investments in internal R&D, and more likely through networking (Carfora et al., 2022) and the joint SME effort in creating relevant innovation infrastructure (e.g. automotive intelligence center) shared by many businesses.

5.3. Limitations and future research steps

These findings are quite interesting from a research perspective and useful from a policy standpoint. However, more can be done with a more thorough approach to eco-innovation that entails a routine collection of data on eco-innovation (not undertaken after European Commission, 2022) which provides an evolutionary perspective on EI in and across countries. Moreover, the data could be collected separately for micro-enterprises, as they will never have the same innovation capacity of larger firms (SMEs). Identification and study of different industries/sectors (e.g. manufacturing vs services, or high-tech industries vs traditional industries) will also help identifying their specific contributions to eco-innovation which are likely to diverge significantly. The case of more advanced economies also needs to be included to provide a clearer pathway to development of eco-innovations in catching-up economies. The study of developing and emerging economies would also be relevant to understand whether a different pathway to eco-innovation is available for this large set of countries that are also called to contribute to the general sustainability of planet Earth.

CRediT authorship contribution statement

Mario Davide Parrilli: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Formal analysis, Conceptualization. **Merima Balavac-Orlic:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Data curation. **Dragana Radicic:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis.

Declaration of competing interest

On behalf of the authors, I can confirm that we have no conflict of interest in relation to the current paper submission. We do not face any financial or personal relationships with other people or organizations (justified by employment reasons, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding) that could inappropriately influence (bias) our work.

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Data availability

The data that has been used is confidential.

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