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Environmental innovation across SMEs in Europe

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ABSTRACT

This paper focuses on the relation between business innovation modes and environmental innovation. Over time firms have recognized the importance of prioritizing innovation to gain competitive advantages in open markets. Yet, in more recent times with the more recent international agreements on environmental sustainability (rounds in Doha in 2004; Copenhagen in 2009; Paris in 2016; and Glasgow in 2021), innovation needs to be guided through new boundaries and requirements that individual businesses and the business system as a whole face. One of these boundaries is nature and its resources which require significant protection as part of the international priority agenda on climate change agreed by most countries with the 2016 Paris Agreement on the Environment and recently confirmed with COP26. As firms are found to adopt alternative archetypical strategies of innovation, some science-driven (STI innovation mode) and others practice-driven (DUI innovation mode), we investigate whether any of these strategic modes is beneficial in relation to the capacity of the firms to produce eco-innovations, and which one is more beneficial in relation to which type of eco-innovation (e.g. technological and non-technological innovation). This analysis is seen in relation to the size of the firms as SMEs typically rely on practice and interactive-based innovation activities (DUI mode). This may help design environment protection-orientated policies that focus on specific drivers, thus making policy action efficient and effective. The analysis is based on the Community Innovation Survey (CIS) database for European countries. Our findings support the view that both STI and DUI drivers support eco-innovation through technological nuances that work also in the specific case of SME environmental innovation.

1. Introduction

Environmental protection and sustainability have become a priority across the world economy from the Bruntland Report (WCED, 1987) and Rio de Janeiro earth summit in 1992 and the following international agreements in Kyoto, Doha, Copenhagen up to the recent Paris Agreement in 2016 and COP26 in Glasgow. Environmental protection and the control of climate change have become crucial goals of the United Nations (United Nations, 2021). Simultaneously, innovation has become a clear priority for economic development as it represents the key driver for competitiveness in the current globalized markets (Hollanders et al., 2009; Edler and Fagerberg, 2017). However, innovation and environmental sustainability do not necessarily go hand in hand. The "weak sustainability" approach would entail the possibility to compensate for part of the depleted natural resources for some other form of capital (i.e. human capital or physical capital) within the overall "constant capital rule" (Wall, 2013). This dilemma motivates our work on the relation between firm-level innovation and environmental sustainability. In this study we utilize the "business innovation modes" framework that is derived from the literature on innovation systems (Jensen et al., 2007; Amara et al., 2008; Asheim and Parrilli, 2012) to analyze critical behaviours and strategies of innovation across firms that belong to specific production and innovation systems. We explore whether the two archetypical business innovation modes (science and technology based or STI, and innovation based on learning-by-doing, by-using and by-interacting or DUI) are critical for environmental innovation and to what extent (see Jensen et al., 2007; Parrilli et al., 2020). In addition, we analyze whether the behaviour of small and medium-sized enterprises (SMEs) differs from the general trend and to what extent. This evidence can help identify policy actions that might have an impact on eco-innovation across SME.

In this study we produce new knowledge within the literature on innovation systems and business innovation modes about what kind of archetypical innovation strategies work best to generate eco-innovation.

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The contribution of this work is fourfold as we study 1) whether the practice-based innovation mode (DUI), that is typically adopted by most SMEs (Amara et al., 2008; Chen et al., 2011; Apanasovich et al., 2016; Thomä, 2017), is effective in generating eco-innovations; 2) whether the more expensive science and technology-based mode (STI) is the most effective in general and across SMEs. We also check 3) whether these modes have a differentiated impact depending on the type of eco-innovation (e.g. product vs process or non-technological innovation) as it is established in the broader literature on broader innovation (Amara et al., 2008; Parrilli; Alcalde, 2016; Trott and Simms, 2017). Moreover, 4) we assess a large set of European countries, thus deliver an assessment that goes beyond context/country specificities of the majority of studies on business innovation modes (Jensen et al., 2007; Fitjar and Rodriguez-Pose, 2013; Apanasovich et al., 2016; Lee and Miozzo, 2019) and on environmental innovation (De Marchi, 2012; Del Rio et al., 2017; Demirel and Kesidou, 2019; among others).

In the next section, the debate around business innovation modes is presented before delving into a more thorough discussion of the scholarly work on environmental innovation within the economics literature that ends up with our main arguments shaped through a set of relevant hypotheses and propositions. The methodological section follows together with the empirical section while a final section of discussion, concluding remarks and policy implications completes this work.

2. Business innovation modes and environmental innovation

2.1. Innovation systems and business innovation modes

The literature on innovation systems has recently spawned a strand of scholarly contributions on the archetypical business innovation modes that are implemented in different countries and regions and that represent different entrepreneurial approaches to innovation and their success obtained at different latitudes (Jensen et al., 2007; Amara et al., 2008; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Apanasovich et al., 2016; Thomä and Zimmermann, 2020). Some businesses, regions and countries are particularly good in investing resources in R&D and scientific human capital, and in collaboration with universities and research centers (the STI mode), while others are effective in reaping the benefits of more experiential and collaborative types of innovation modes (DUI). The former are usually the most advanced countries and regions, while the second refers to catching-up economies that invest fewer resources in R&D (Parrilli et al., 2020; Hervas-Oliver et al., 2021). However, there may be context-specific reasons for such variations that lead to similar success levels. It is the case of Norway and Denmark that focus particularly on the DUI mode, while Sweden and Finland traditionally invest more resources in R&D and scientific human capital (Edquist, 2004; Asheim and Parrilli, 2012).

This literature on business innovation modes has produced a large number of contributions that focus on a range of aspects that include the special approach taken in traditional industries, e.g. food industry (Trott and Simms, 2017), and in knowledge-intensive business services (Lee and Miozzo, 2019), the different approach taken by high technology vs traditional industries in emerging economies (Chen et al., 2011, for China), the importance of global vs local STI and DUI collaborations (Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde, 2016), a peculiar approach taken by small and medium-sized enterprises (Thomä, 2017; Thomä and Zimmermann, 2020; Parrilli and Radicic, 2021) or the innovation mode typically taken by firms in a range of regions classified among leading, strong, moderate and modest innovators (Parrilli et al., 2020) (see Table 1 for a review).

Every contribution in this area has opened reflections and queries that lead to more studies on key factors for innovation across businesses, regions and countries. Among the not yet investigated research areas in this strand of literature is the effort of businesses in the field of environmental innovation. This has become a priority for all countries and production systems that plan to compete today and in the future, and that want to respond to the Bruntland principle of: "*Development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (WCED, 1987: 8, 43). This effort would help scholars to understand whether the archetypical innovation modes are effective in relation to eco- innovations, and particularly within small and medium-sized enterprises.

Table 1
Synthetic literature review on business innovation modes.

	Key insight	Geographical context	Scholars
1	The importance of the DUI mode	Broad geography; Denmark	Lundvall (2007); Jensen et al. (2007)
2	Combination of STI and DUI modes	Denmark; Norway, Sweden, Spain, Europe	Jensen et al. (2007); Isaksen and Karlsen (2010); Isaksen and Nilsson (2013); Parrilli and Alcalde-Heras (2016); Parrilli et al. (2020)
3	DUI mode across SMEs	Canada; Spain, Germany, United Kingdom, Europe	Amara et al. (2008); Parrilli and Elola (2012); Thomä (2017); Trott and Simms (2017); Parrilli and Radicic, 2021
4	Business innovation modes in different industries (high-tech vs low-tech and services)	China, Spain, United Kingdom	Chen et al. (2011); Parrilli and Elola (2012); Trott and Simms (2017); Lee and Miozzo (2019)
5	Technological nuance of modes	Spain	Parrilli and Alcalde-Heras (2016); Apanasovich et al. (2016, 2017)
6	STI and DUI across Global vs Local collaborations	Norway, Spain	Fitjar and Rodriguez-Pose (2013); Parrilli and Alcalde-Heras (2016)
7	Approach in innovation leaders vs moderate and modest innovators	Europe	Parrilli et al. (2020)
8	Specific approach in catching-up countries	Eastern and Southern Europe	Hervas-Olivier et al. (2021)

Source: own elaboration.

2.2. Key drivers of eco-innovation

The work on eco-innovation is rather recent. Some contributions highlighted the existence of different types of drivers of eco-innovation at the macro, meso and micro level (Díaz-García et al., 2015). Other contributions stress the importance of connecting various sources of knowledge that help supporting this environmentally friendly business effort (Horbach et al., 2013; Ghisetti et al., 2015). This is seen as particularly important in relation to R&D collaborative activities in which universities, suppliers and knowledge-intensive business services are crucial agents (De Marchi, 2012). This latter contribution also identifies a certain substitution effect between such external collaborations in R&D and any internal effort made by the business itself in relation to environmental innovations (De Marchi, 2012). In general, most environmental innovation activities are found to be positively correlated with the financial performance of the firms (Marín-Vinuesa et al., 2020).

Among the critical drivers, customer demand is included as more sensitive customers will raise their expectations of the environmental quality of the goods and services provided by producers. Scholarly contributions confirmed the importance of customers demand not only for the implementation of product eco-innovation in general, but also for the novelty/radicalness of such eco-innovations (Kammerer, 2009; Demirel and Kesidou, 2019; Costantini et al., 2020). Sometimes, firms implement environmental innovations as a means to apply minimal requirements of corporate social responsibility (CSR) that respond to their customers' sensitivity; however, the effective level of investment in environmentally friendly practices depend more on cost savings, firms' organizational capabilities, and stricter regulations which are indicated as key levers for the impact of customer demand on environmental innovation (Kesidou and Demirel, 2012, 2019; Huang et al., 2016). Government regulation and policy are also identified as critical factors of environmental innovation across businesses by a number of scholars (Kammerer, 2009; Rennings and Rammer, 2011; Huang et al., 2016), although these may have a differentiated impact depending on the type of eco-innovation (e.g. positive for sustainable transport mobility and negative for water management, see Rennings and Rammer, 2011) (see Table 2 for a review).

2.3. Hypotheses development

The literature on STI and DUI innovation modes has established clear connections between the archetypical innovation modes and different types of innovation output -e.g. technological (product and process) and non-technological (marketing and organizational innovation, OECD, 2005) (see Amara et al., 2008; Chen et al., 2011; Apanasovich et al., 2016; Parrilli and Alcalde, 2016; Thomä and Zimmermann, 2020). However, this literature did not discuss yet the connection between these innovation modes and their impact on eco-innovations. In this case, we have a blue ocean of research that can be launched as a mean to identify whether firms and SMEs in particular pay attention to this objective, and whether any of these archetypical innovation modes (i.e. their effective strategies) is more successful in producing specific eco-innovation outputs (e.g. product, process and non-technological innovation).

The question is whether businesses of all sizes and countries focus on eco-innovations that are defined as improvements in goods, processes, organization and marketing through a reduced production of pollution or by reducing the use of materials, energy, water, etc. or through the utilization of recycled water, materials and waste within the firms or across end-users (CIS, 2014: section 13). In particular, we focus on whether the application of STI and DUI modes generates impact not only

Table 2
Drivers of environmental innovation across businesses.

	Key insights	Geographical context	Scholars
1	There are different levels where environmental innovation takes place - macro, meso and micro	Spain	Díaz-García et al. (2015)
2	Scientific and technological institutions matter for environmental innovation	Italy; Germany	De Marchi (2012); Horbach et al. (2013); Ghisetti et al. (2015);
3	Demand and customer needs positively drive environmental innovation	Austria, France, China, Italy	Kammerer (2009); Demirel and Kesidou (2012; 2019); Huang et al. (2016); Kiefer et al. (2019); Costantini et al. (2020)
4	Government regulation influences directly the generation of environmental innovation	Austria, Germany, China	Kammerer (2009); Rennings and Rammer (2011); Huang et al. (2016)
5	Importance of pressure of international agreements and commitment on lending for environmental innovation	Italy, Germany	Cainelli et al. (2012); Horbach et al. (2013); Ghisetti et al. (2015)
6	Environmental benefits within the firm represent process innovation, while benefits for end-users represent product innovation	Italy, Spain	Ghisetti and Rennings (2014); Garcés-Ayerbe et al. (2016); Greco et al. (2020)
7	Environmental innovation has a positive impact on economic/financial performance	Spain	Marín-Vinuesa et al. (2020); Madaleno et al. (2020)

Source: own elaboration.

on broad innovations, but also on specific environmental innovations (question 13.2 in 2014 questionnaire). In this way, our analysis echoes the work of Garcés-Ayerbe et al. (2016) in that we try to shed light not only on eco-innovations as a product (e.g. green patents), but on the whole set of potential eco-innovations that include also environmentally friendly new practices, organizational and commercial methods (see also Ghisetti and Rennings, 2014; Greco et al., 2020). Within the STI and DUI innovation framework, we expect the businesses that focus on innovation to use both modes in a significant way. STI drivers (R&D and collaboration with universities) are likely to be involved as there is a growing international requirement to consider relevant environmental aspects/benefits in most R&D-led innovation projects which are financed under public (e.g. Horizon-Europe/European Union, or the UN Sustainable Development Goals) or private schemes leading to the use of venture capital, bank loans and even stocks (Cainelli et al., 2012; De Marchi, 2012; Horbach et al., 2013; Ghisetti et al., 2015). However, from the previous studies in the literature on business innovation modes we know that STI drivers tend to have little impact on process innovation and non-technological innovation (i.e. organizational and marketing) as they are eminently focused on product innovation (Apanasovich et al., 2016; Trott and Simms, 2017; Parrilli et al., 2020). Thus, we hypothesize that these STI drivers are unlikely to generate a significant impact on environmentally friendly process, organizational and marketing innovations, such as the reduced use of resources, pollution levels and the likes (e.g. through the use of filters in polluting industries, or through a non-paper/poster-based marketing campaign led online). Simultaneously, the above literature on innovation modes stresses that STI drivers have the strongest impact on "product innovation" (Apanasovich et al., 2016; Parrilli; Alcalde, 2016; Parrilli et al., 2020), thus in this case we expect STI to produce strong impact on product eco-innovations, such as the production of e-vehicles, or the creation of longer duration (batteries for) electronic equipment such as laptops, mobile phones and tablets. As a result, the work of science and technology-based agents (e.g. universities, private science labs) and internal R&D generate goods and services that can deliver effective environmental benefits. These eco-innovations have an impact on end-users as they will not need to buy these goods frequently, but may stick to their purchases for a longer time span (e.g. batteries), as these will be more energy efficient (e.g. new houses and cars).

On these bases, we suggest the following general hypotheses:

H1a. The application of STI drivers is positively correlated with product eco-innovations.

H1b. The application of STI drivers is not correlated with process, organizational and marketing eco-innovations.

In relation to the DUI innovation mode, we argue that this mode can also be very effective. In this case, firms that focus on innovation are likely to implement teamwork and purchase new machinery and equipment – typical DUI practices within the firm-, as well as effective supply chain collaborations that impact on the efficient use of resources – DUI practice outside the firm - (Lam, 2004). This practice is likely to generate eco-innovations thanks to the collective responsibility towards the process and organizational method that lead to the production of final goods/services. For instance, ISO14001 and other certifications tend to guarantee the control of quality from the origin of materials and resources (see Inoue et al., 2013). Moreover, these practices promote a reduction in the use of natural resources, such as lumber in the furniture industry, or fuel in the energy industry by means of developing more efficient machinery and better organizational practices (e.g. plant layout). They may also lead to increases in productivity of existing technologies in renewable energies such as through the implementation of more efficient gearboxes and generators in the wind energy industry. Simultaneously, these firms are bounded by international regulations in relation to the quality of goods and services they provide to end-users (Demirel and Kesidou, 2019; Costantini et al., 2020). For instance, the energy industry supply chain is organized in a way that helps reducing the dispersal of energy through the grid (e.g. smart energy system in and across countries), and to deliver new tools for energy-efficient use of equipment in the household (e.g. smart meter reading in the house). In a way, these changes generate process-based and organizational-based eco-innovations that entail impact also on the way these eco-innovations are marketed (i.e. marketing-based eco-innovations; see Kiefer et al., 2019). As a result, we propose the following general hypotheses:

H2a. The application of DUI drivers is not correlated with product eco innovations.

H2b. The application of DUI drivers is positively correlated with process, organizational and marketing eco-innovations.

Fig. 1 shows the expected direct impact of STI drivers on product eco-innovation and DUI drivers on process and non-technological (organization and marketing) innovations. Instead, the impact of STI drivers on process and non-technological innovations, and DUI drivers on product innovation is indetermined.

Echoing previous work on small and medium-sized enterprises (SMEs) and innovation (Parrilli and Elola, 2012; Thomä, 2017; Parrilli and Radicic, 2021; Alhusen and Bennat, 2021), we want to discuss the peculiar approach that SMEs take on production and innovation practices that generate some type of eco-innovations. While Del Rio et al. (2017) identified a lower capacity of SMEs (vis-à-vis large firms) to produce eco-innovations, Marin et al. (2015) identified a significant SME heterogeneity in terms of their access and capacity to eco-innovate (see Table 3 for a review). Some become "green champions" while others face significant barriers to eco-innovation, and others are "non-eco-innovators". Such classification is related to both geographical and industry specializations although not as strictly as expected. Only the "green innovators" are typically found in industries that are non-emission intensive and are strongly regulated. Klewitz and Hansen (2014) follow a similar line of argument, but more in terms of environmental strategies and sustainability-oriented innovations (SOIs). Daddi et al. (2012) observed the heterogeneity of SME environmental focus across different industrial districts in Italy and found different eco-innovation approaches and outcomes, while the general eco-innovation effort is usually completed by successful economic performance. Triguero et al. (2013) argue that research collaborations with universities produce SME eco-innovations in goods and services, while supply-chain collaborations promote process and organizational eco-innovations. They also found that regulations and subsidies do not favour environmental innovations. Cecere et al. (2020) found that despite the growing demand for eco-innovation and regulatory interventions, the lack of access to funding and subsidies prevents SMEs from accelerating their contribution to eco-innovation. Networking and agglomeration economies are found not to matter much for SMEs, while instead being relevant for larger firms (Cainelli et al., 2012).

In this study, we expect SMEs to focus less on STI drivers to produce eco-innovations. This is related to the size of their operations and the difficulties to engage in costly and lengthy projects with very selective outputs (i.e. eco-innovations) that will come far in the future (Bennat and Sternberg, 2020). In addition, the lack of highly specialized human capital within SMEs reduces their absorptive capacity, which is also associated to the firm investment and return on STI activities (Zahra and George, 2002). This may vary across industries (Daddi et al., 2012; Klewitz and Hansen, 2014; Marin et al., 2015), though this correlation is not expected to be strong. Instead, we argue that SMEs are more likely to engage in internal and external DUI practices (e.g. implement ISO 14, 000 certified environmental-friendly practices) to attain significant eco-innovations (Triguero et al., 2013). It is the way SMEs typically learn and innovate; thus they are likely to implement it also when producing eco-innovations (e.g. ways to reducing the use of materials and the generation of waste). For this reason, we set two general propositions that can be ascertained through the successive descriptive statistics:

P1: SMEs tend to adopt more significantly the DUI innovation mode than the STI innovation mode.

P2: SMEs tend to implement more significantly process and non-technological eco-innovations than product eco-innovations.

However, more specifically and according to previous studies on innovation modes (Parrilli and Radicic, 2021) and on environmental innovation (Triguero et al., 2013), we expect SMEs to be able to reap benefits from STI drivers in relation to product-based eco-innovation but not so much in relation to process and non-technological innovation. Instead, we expect to find the DUI drivers to generate impact on eco-innovation through process, organizational and marketing innovation. Therefore, we formulate the following hypotheses:

H3a. The application of STI drivers is only significantly correlated to product eco-innovations across SMEs.

H3b. The application of DUI drivers is positively correlated to process, organizational, and marketing eco-innovation across SMEs.

3. Methodology

3.1. Sample and data

The empirical analysis is drawn upon firm-level data form the Community Innovation Survey (CIS), which have been used extensively in the innovation literature (Cassiman and Veugelers, 2002; Ballot et al., 2015) and eco-innovation studies (Madaleno et al., 2020; Biscione et al., 2021). CIS is based on harmonized questionnaire based on the Oslo Manual (OECD, 2005) with methodological recommendations specified by the Eurostat (CIS Quality Report, 2014). CIS has its advantages and disadvantages; yet it is characterized by high response rate, standardized methodology and data of high quality that enables comparisons across countries. We use the CIS 2014 dataset that covers the period 2012–2014 and includes 10 EU countries from South and Eastern Europe (Greece, Portugal, Croatia, Romania, Bulgaria, Estonia, Slovakia, Hungary, Latvia, Lithuania). These are the only EU countries that delivered good responses on the environmental part of the survey. Overall, the CIS2014 gives us an opportunity to investigate environmental innovation as, after CIS2008, it is the only CIS survey that incorporates questions on firms' environmental strategies and their connections to different types of innovations. CIS2014 have already been used in the innovation literature (Parrilli et al., 2020), but investigation of eco-innovation appears only recently, and it is still limited (Madaleno et al., 2020; Biscione et al., 2021).[1] A number of effective observations (used in empirical models) for each country are shown in Table 4.

3.2. Dependent variables

Table 5 shows descriptions of the dependent and independent variables together with descriptive statistics in the full sample and for SMEs. The first dependent variable is *Product eco-innovation*, which is equal to 1 if a firm introduced product innovations that generate environmental benefits, and zero otherwise (this definition is also used in Biscione et al., 2021). *Process eco-innovation* is equal to 1 if a firm introduced process innovations that generate environmental benefits, and zero otherwise (Biscione et al., 2021). *Organisational eco-innovation* is equal to 1 if a firm introduced organisational innovations that generate environmental benefits, and zero otherwise (Biscione et al., 2021). *Marketing*

[1] Madaleno et al. (2020) investigate the impact of eco-innovation on firm performance measured as a turnover growth. Thus, it belongs to a different stream of research, than our study. Some countries report none or very few observations for some variables (Parrilli et al., 2020; Biscione et al., 2021). The latter is the reason we could not include Czech Republic in our sample, as there were too many missing values.

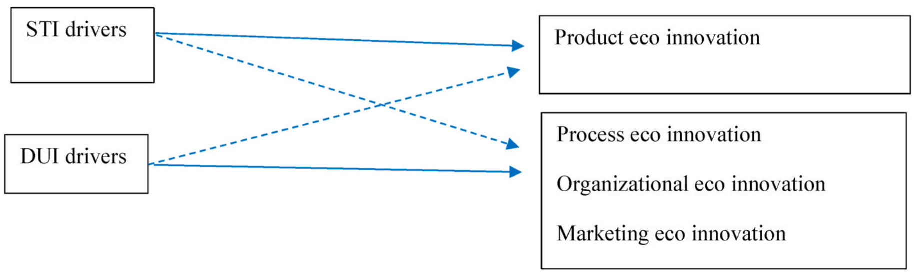

Fig. 1. STI and DUI drivers and eco-innovation outputs among SMEs.

Table 3
Drivers of eco-innovation across SMEs.

	Key insights	Geographical context	Scholars
1	Heterogeneity in the production of eco-innovations among SMEs	Spain, Europe	Del Rio et al. (2017)' Marin et al. (2015)
2	Sectorial bias in eco-innovation	Italy; Broad	Marin et al. (2015); Klewitz and Hansen (2014)
3	Lower contribution to eco-innovation due to difficult access to finance	Italy	Cecere et al. (2020)
4	Technological nuance of eco-innovation	Europe	Triguero et al. (2013)
5	Networking and agglomeration economies do not matter much for SME eco-innovation	Italy	Cainelli et al. (2012)
6	Eco-innovation produces good economic performance also across SMEs	Italy	Daddi et al. (2012)

Source: own elaboration.

Table 4
Number of observations by country – full sample and SMEs.

Country	Full sample	SMEs
Bulgaria	665	556
Croatia	523	421
Estonia	215	182
Greece	683	582
Hungary	335	183
Lithuania	1125	909
Latvia	217	170
Portugal	2376	2105
Romania	245	158
Slovakia	560	314
Total	***6944***	***5580***

eco-innovation is equal to 1 if a firm introduced marketing innovations that generate environmental benefits, and zero otherwise.

3.3. Independent variables

Regarding explanatory variables of interest, we follow the classification of STI and DUI innovation modes developed by Jensen et al. (2007). The advantage is that, unlike studies that measure STI and DUI based on different types of collaboration (Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde, 2016; Haus-Reve et al., 2019), our investigation also considers firms' internal activities associated with STI or DUI innovation modes (Parrilli et al., 2020; Parrilli and Radicic, 2021). The *STI* variable is equal to 1 if firms either undertake (internal and/or external) R&D activities or cooperate with higher education institutions and government research centers, and zero otherwise. Collaboration is deemed to be an important explanatory variable for environmental innovation in the literature (Wagner, 2008; Mazzanti and Zoboli, 2009). The *DUI* variable includes in-house activities (i.e. in-company training, design, and market introduction of innovations) and cooperation with suppliers, customers, competitors and consultants. This variable takes value of 1 if any of these activities or types of cooperation occurs, and zero otherwise.

To estimate the individual and joint effects of STI and DUI, we create treatment variables with the following values:

- treatment = 0 if a firm adopted neither STI nor DUI innovation modes (see Table 5 for the number of firms in each treatment category);
- treatment = 1 if a firm only adopted the STI mode;
- treatment = 2 if a firm only adopted the DUI mode;
- treatment = 3 if a firm adopted the combined STI + DUI mode.

3.4. Control (matching) variables

Regarding control (matching) variables, one set of variables controls for determinants specific to environmental innovation. These are all binary variables that controls for incentives for introduction of environmental variables. CIS2014 incorporates questions on different incentives for the introduction of environmental innovation, ranging from the those imposed by government regulations and incentives (regulation and taxes-present and anticipated, grants or public procurement) to those incentivized by the market and corporate image (reputation and expected market demand). These determinants have been extensively studied in the literature (see the review in Horbach et al., 2012). Regulation, both present and anticipated, have been identified in the empirical literature as one of the most important drivers of the environmental innovation (Del Río, 2009; De Marchi, 2012; Chassagnon and Haned, 2015; Greco et al., 2020). Likewise, demand and corporate image is found to be important factor for introduction of environmental innovation (Kammerer, 2009; Chassagnon and Haned, 2015). These incentives are included in our models as the dummy variables which measure important factors in firms' decision to engage in environmental innovation (at either high or medium levels): *Regulation*, *Taxes*, Grants, *Demand,* and *Reputation.* Variable *Procedure* is equal to 1 if a firm has procedures in place to identify and reduce environmental impacts (and zero otherwise).

We control for firm characteristics, such as firm size (in the full sample, exporting and belonging to an enterprise group. Firm size is one of the traditional control variables in the empirical investigation of different aspects of innovation outputs in general (Cassiman and Veugelers, 2002; Parrilli et al., 2020) and environmental innovation in particular (Veugelers, 2012; Borghesi et al., 2015; Greco et al., 2020). In our study, firm size is measured by using a dummy variable for SMEs (Greco et al., 2020; Parrilli et al., 2020). In addition, we control for the exporting status of a firm, given that the literature shows that being an exporter results in a higher level of innovation output (Ghisetti et al., 2015; Greco et al., 2020), as exporting firms might face tougher competition in international markets. Empirical models also control for firms belonging to an enterprise group (Ghisetti, 2017; Marzucchi and Montresor, 2017). Firms that are part of an enterprise group might have

Table 5
Descriptive statistics - full sample and SMEs.

Variables	Variable description	Full sample	SMEs
		Percentage	Percentage
Treatment	A categorical variable defined as:		
	Neither STI nor DUI innovation modes (treatment = 0)	20.12	22.29
	only the STI mode (treatment = 1)	9.45	9.68
	only the DUI mode (treatment = 2)	30.3	31.36
	the combined mode STI + DUI (treatment = 3)	40.41	36.67
Outcome variables			
		Mean (stan. deviation)	**Mean (stan. deviation)**
Eco product	Dummy variable (DV) = 1 if a firm introduce a product (good or service) innovation with environmental benefits; zero otherwise.	0.391 (0.488)	0.372 (0.483)
Eco process	DV = 1 if a firm introduce a process innovation with the environmental benefits; zero otherwise.	0.498 (0.500)	0.470 (0.499)
Eco organisational	DV = 1 if a firm introduce an organisational innovation with any environmental benefits; zero otherwise.	0.252 (0.434)	0.243 (0.429)
Eco marketing	DV = 1 if a firm introduce a marketing innovation with the environmental benefits; zero otherwise.	0.113 (0.317)	0.109 (0.311)
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	0.775 (0.418)	0.758 (0.428)
Group	DV = 1 if a firm belongs to enterprise group; zero otherwise	0.428 (0.495)	0.339 (0.473)
SME	DV = 1 if a firm is small or medium-sized enterprise; zero otherwise	0.804 (0.397)	
Regulation	DV = 1 if existing environmental regulations is of high or medium importance in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.684 (0.465)	0.662 (0.473)
Taxes	DV = 1 if existing environmental taxes/ charges/fees is of high or medium importance in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.531 (0.499)	0.514 (0.500)
Grants	DV = 1 if government grants, subsidies or other financial incentives for environmental innovations is of high or medium importance in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.315 (0.464)	0.310 (0.463)

Table 5 (*continued*)

Variables	Variable description	Full sample	SMEs
		Percentage	Percentage
Demand	DV = 1 if current or expected market demand for environmental innovations is of high or medium importance in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.482 (0.500)	0.467 (0.499)
Reputation	DV = 1 if improving firm's reputation is of high or medium importance in driving enterprise's decisions to introduce innovations with environmental benefits; zero otherwise	0.745 (0.436)	0.732 (0.443)
Procedure	DV = 1 if a firm have procedures in place to regularly identify and reduce your enterprise's environmental impacts; zero otherwise	0.464 (0.499)	0.395 (0.489)
High tech	DV = 1 if a firm belongs to a high-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise.	0.020 (0.139)	0.016 (0.124)
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.	0.122 (0.311)	0.108 (0.251)
Medium low tech	DV = 1 if a firm belongs to a medium low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise.	0.217 (0.418)	0.225 (0.330)
Low tech	DV = 1 if a firm belongs to a low-tech sector according to NACE2 classification in the period 2012–2014; zero otherwise	0.246 (0.431)	0.247 (0.378)
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	0.153 (0.360)	0.156 (0.363)
Less knowledge intensive services (LKIS)	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	0.161 (0.368)	0.168 (0.374)
Other sectors	DV = 1 if a firm belongs to other sectors according to NACE2 classification in the period 2012–2014; zero otherwise	0.081 (0.274)	0.080 (0.271)

access to external knowledge of other firms in the group, which would enhance absorptive capacity of the focal firms, and consequently, increase the likelihood of eco innovation.

Finally, sectoral effects were controlled by including dummies based on the Eurostat classification of manufacturing and service sectors at NACE 2-digit level according to technological intensity: high-tech, medium-high, medium-low and low-tech, knowledge-intensive services (KIS), less knowledge-intensive services (LKIS), and other sectors (Chen et al., 2011; Ballot et al., 2015). To control for country effects, we include dummy variables for each country (Slovakia being the reference category).[2]

3.5. Empirical strategy

A recent literature on STI and DUI innovation modes raised an issue of their endogeneity, arising from the nature of their components, i.e. endogeneity of internal and external R&D activities (Duso et al., 2014), and a potential reverse causality 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). To account for endogeneity of innovation modes, our empirical strategy relies on the estimation of treatment effects, in particular, the average treatment effects on the treated (ATT).

In a cross-sectional setting like ours, treatment effects can be estimated either using the instrumental variable (IV) approach or matching estimators. The former requires valid instrument(s) for the treatment variable(s), which is often difficult to find, in particular in the stream of research on a firm-level innovation (Love et al., 2014; Parrilli and Radicic, 2021). Matching estimators have few advantages over other cross-section empirical strategies. Compared to the IV approach, matching does not require valid instruments and it does not make any assumptions about the functional form of the outcome equation (Czarnitzki et al., 2007). However, the main disadvantage of matching estimators is the assumption of unconfoundedness or selection on observables. This means that matching estimators assume that unobserved heterogeneity is unlikely to arise. In practice, researchers include a large number of matching (control) variables to mitigate unobserved heterogeneity (Czarnitzki et al., 2007).

Given that firms might simultaneously engage in STI and DUI modes, we estimate treatment effects in the multiple treatment contexts through the matching approach with multiple treatments introduced by Lechner (2001). We have M+1 treatments, whereby treatment = 0 denotes firms that do not engage in either STI or DUI; treatment = 1 denotes engagement only in STI mode only; treatment = 2 refers to engagement only in DUI mode; and treatment = 3 refers to engagement in both innovation modes. The average treatment effect on the treated (ATT) effect is then calculated as:

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

Where m denotes the treatment level, l represents the comparison group (the treatment level to which m is compared, termed matched controls by Czarnitzki et al., 2007), and Y^m and Y^l denote outcomes in states m and l respectively. To estimate the model in equation (1), we employ the inverse probability of treatment weighting regression adjustment (IPWRA) estimator.

The IPWRA estimator belongs to a group of matching estimators that have the double-robust property. Double robustness implies that either the treatment model or the outcome model (or both) has to be correctly specified for the estimator to produce consistent treatment effects (Hirano et al., 2003). The use of the IPWRA estimator requires three steps. First, for each firm in the sample, the treatment model estimates the propensity score, which is the probability of a treatment assignment. Given that we evaluate multiple treatment effects, the propensity scores are estimated by a multinomial logit model, incorporating all four treatment levels: neither STI nor DUI; only DUI; only STI; and both.[3] The choice of the model is motivated by the nature of our treatment variable, which has more than two outcomes with no natural ordering. The propensity scores enable firms to be matched within each treatment level. Second, regressions are estimated by the logit model, because the outcome variables are binary indicators, in which the inverse of the estimated propensity scores are used as weights on covariates X and our treatment dummies. Third, from each of these regressions, the ATT effect is computed as the difference in the weighted averages of the predicted outcomes (for technical details, see Wooldridge, 2010). This three-step approach provides consistent estimates given the underlying assumption of the independence of the treatment from the predicted outcomes once covariates are modelled in steps 1 and 2. We report valid standard errors (of the Huber/White/sandwich type) which take into account that the estimates are computed in a three-step approach (Emsley et al., 2008).

4. Empirical results

4.1. Descriptive statistics and correlation coefficients

Table 5 shows descriptive statistics and variable description. On average, the full sample as well as the specific SMEs sample focus more on process eco-innovation with around 50% of the firms engaging in this kind of innovation. Product eco-innovation follows with around 40% of firms. Instead, organizational and marketing eco-innovation attain lower results (25% and 11% respectively). Importantly, these descriptive statistics indicate the emphasis that all firms, including the SMEs, put on technological eco-innovation (i.e. product and process) vis-à-vis non-technological eco-innovation. In relation to the specific case of SMEs, proposition P2 is partially confirmed as process innovations are certainly the most targeted innovation, but product innovation is also developed to a significant extent and certainly more than non-technological innovation. This is explained with the traditional emphasis attributed to technological innovations over non-technological innovations across all classes of firms (Jensen et al., 2007; Fitjar and Rodriguez-Pose, 2013, among others).

The other important descriptive statistics refers to the innovation modes adoption by all firms and by SMEs (see Table 6). We see a balanced approach with a significant number of firms that do not adopt any innovation mode, thus are not yet focusing their activities and objectives on the production of eco-innovations (20% for the whole set of firms, and 22% across SMEs). However, a larger group of firms and SMEs

Table 6
Number of firms by treatment category in full sample and in SMEs.

Treatment level	Number of firms in the full sample	Number of firms in SMEs
=0 (none)	1397	1244
=1 (only STI)	656	540
=2 (only DUI)	2085	1750
=3 (both STI and DUI)	2806	2046
Total	***6944***	***5580***

[2] To avoid the dummy variable trap, one of the country dummies needs to be omitted. The choice of the omitted dummy, called the reference or the base category, is arbitrary (Stock and Watson, 2019, p. 230). Thus, Slovakia has been randomly chosen as the reference category.

[3] Due to a large number of models that are estimated, results from multinomial logit models are not reported but are available upon request. The coefficients in multinomial logit models are not of interest in themselves, as the purpose of specifying the model is to facilitate the estimation of treatment effects by estimating a propensity score needed for the matching procedure (Cattaneo et al., 2013).

adopt either the STI mode, or the DUI mode or even the combined STI&DUI mode (78%–80%). As we expected, a large cohort of firms and SMEs adopt the DUI mode, more traditional, experience- and interaction-based (31–32%) and a smaller cohort adopts the STI mode (9%). This preliminary outcome confirms our proposition P1. However, rather surprisingly a significant proportion of firms and SMEs already adopt the challenging combined STI&DUI mode (40% across the whole sample, and 36% across SMEs). This indicates that a large group of firms, including SMEs, are becoming sensitive to the importance of a wider and more complete approach to business innovation, which in relation to general innovation is proved to be the mode with the highest overall attainments (Jensen et al., 2007; Isaksen; Karlsen, 2010; Parrilli; Alcalde, 2016; Parrilli et al., 2020).

Pearson's correlation coefficients amongst the control (matching) variables are presented in Table 7 (for the full sample) and Table 8 (for SMEs). The correlations in both samples are overall low to moderate, suggesting that multicollinearity is unlikely to occur.

4.2. Econometric evidence

4.2.1. The impact of STI and DUI drivers in general and in relation to SMEs

Table 9 presents empirical results for the full sample, while Table 10 shows results for SMEs. Overall, the impact of STI drivers is significant on product eco-innovation, while it is not significant when it is applied to process, marketing and organizational eco-innovations. As a result, H1a and H1b are both supported. This general outcome is valid also in the case of SMEs, thus also H3a is fully supported. As a consequence, we can affirm that this technological nuance of innovation (Apanasovich et al., 2016; Parrilli; Alcalde, 2016; Trott and Simms, 2017) work also in the case of eco-innovation.

Interestingly, our empirical analysis shows that the combined STI&DUI mode works in all cases, technological and non-technological eco-innovations. This seems to indicate that a work that combines the competences and commitment of all staff within the firms as well as along the supply chain with the skills and capabilities of dedicated R&D personnel and infrastructures are likely to build on one another, helps attaining a higher capacity to generate all types of eco-innovations. In a way, these findings strengthen the arguments made by Jensen et al. (2007), Parrilli and Alcalde-Heras (2016), and Parrilli et al. (2020) about broader innovations as also in the case of eco-innovation, the combined STI and DUI mode builds additional strengths and outputs, favoring a stronger environmental innovation path.

Looking at the impact of the DUI mode, its effects on eco-innovation also varies depending on the type of innovation. This mode is highly significant in the full sample as well as for SMEs ($p < 0.01$), though they are significantly related to eco-innovation when they produce process, marketing and organizational eco-innovations, while they become insignificant when they develop product eco-innovations. As a result, hypotheses H2a, H2b and H3b are confirmed, thus align with previous studies on supply chain-led environmental innovations (Kammerer, 2009; Kesidou and Demirel, 2012, 2019; Huang et al., 2016) and on broader technological innovation (Parrilli and Radicic, 2021). Moreover, in this case, a combined STI&DUI mode is generating a positive sum game, thus generates higher eco-innovations than through the applications of the individual modes separately. This outcome also shows the importance of combining skills and capabilities across the whole personnel, including those focusing on a dedicated R&D activity (Parrilli et al., 2020).[4]

5. Conclusions and discussion

5.1. Main findings

Overall, our analysis produces relevant findings in relation to the impact of specific STI and DUI drivers on the eco-innovation practices and performance of all firms and the SMEs in particular. In this study we have identified important eco-innovation patterns across the whole sample of firms and the SMEs. Small variations are visible across different firm sizes. One of the main findings is about the predominance of technological eco-innovation across firms, and particularly process eco-innovation that is practiced by around 50% of the SMEs. Simultaneously, product eco-innovation is practiced by around 40% of the SMEs. In relation to the modes of innovation there is still a significant percentage of firms that do not adopt any innovation mode (20% across the whole sample and 22% across SMEs). A tiny percentage adopts the STI innovation mode (9%) while the expected majority adopts the DUI mode (32% across SMEs). A very interesting outcome however is that a significant proportion of firms and SMEs are already implementing the STI&DUI mode together (36% of SMEs). In the econometric analysis this combined mode is the most effective across all types of innovation output. These findings show the yet extreme heterogeneity of firm/SME behavior in relation to the new environmental objectives set by the Paris 2016 and COP26 Agreements on Climate Change 2016, and the United Nations Development Goals (Daddi et al., 2012; Marin et al., 2015; Del Rio et al., 2017).

Our second main finding is about the technological nuances of both innovation modes for eco-innovation. STI drivers matter especially for product eco-innovations, while not at all for process, organizational and commercial innovation. This clarifies the focus of R&D activities and university-industry collaborations towards product eco-innovations that help the firm to save on materials, recycle materials, and pollute less (De Marchi, 2012; Triguero et al., 2013; Ghisetti et al., 2015). This illustrates that STI drivers and activities tend to be designed and developed in-house by scientists that are likely to pay limited attention to the demands of buyers and consumers. This indicates significant margins for improvement and impact at the societal level to meet the objectives designed by those global agreements in pro of environmental sustainability. Instead, DUI drivers matter for process, organizational and commercial eco-innovation but not so much for product eco-innovation. This applies particularly to the case of SMEs and it is expected as SMEs innovate by means of practice and supply chain interactions that help them improve their production process in ecological terms (Triguero et al., 2013; Demirel and Kesidou, 2019; Costantini et al., 2020). Overall, the nuances of innovation (Parrilli and Alcalde, 2016; Parrilli et al., 2020) work also in relation to eco-innovation. Notwithstanding these technological nuances, the combined STI&DUI mode is the most effective mode in all types of eco-innovation as shown also in relation to broader innovation (Jensen et al., 2007; Isaksen; Karlsen, 2010; Chen et al., 2011; Apanasovich et al., 2016). These results also apply to different firm classes as no large variations are found between the whole sample and SMEs. And yet we know that they are implemented by a segment of firms (36% across SMEs and 40% across the whole sample). This shows the important margins for improvement in the approach to eco-innovation across a large majority of firms and particularly across

[4] For robustness check, we re-estimated the models using the Inverse Probability Weighting (IPW). The difference between this estimator and our preferred estimator (that is, IPWRA) is that the latter has a double robustness property (see Section 3.5) which is not the case with the IPW. The treatment effects from the IPW are shown in Table A1 for the full sample and in Table A2 for SMEs. Qualitatively, the results using the IPW are the very similar as our main results reported in Tables 9 and 10.

Table 7
Correlation matrix for the full sample.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Group	1.000								
(2) Exports	0.123	1.000							
(3) SME	−0.364	−0.081	1.000						
(4) Regulation	0.041	0.008	−0.093	1.000					
(5) Taxes	0.012	−0.002	−0.067	0.636	1.000				
(6) Grant	−0.034	−0.040	−0.020	0.328	0.379	1.000			
(7) Demand	0.041	0.052	−0.060	0.365	0.339	0.445	1.000		
(8) Reputation	0.031	−0.008	−0.060	0.469	0.383	0.286	0.447	1.000	
(9) Procedure	0.253	0.100	−0.279	0.244	0.173	0.107	0.166	0.179	1.000

Table 8
Correlation matrix for SMEs.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Group	1.000							
(2) Exports	0.093	1.000						
(3) Regulation	0.011	−0.003	1.000					
(4) Taxes	−0.007	−0.016	0.645	1.000				
(5) Grant	−0.047	−0.049	0.336	0.374	1.000			
(6) Demand	0.013	0.034	0.366	0.344	0.457	1.000		
(7) Reputation	0.005	−0.010	0.468	0.387	0.293	0.449	1.000	
(8) Procedure	0.182	0.073	0.221	0.156	0.112	0.158	0.165	1.000

Table 9
Estimation results from the IPWRA estimator - full sample (N = 6944)[a].

Types of innovation		STI vs none	DUI vs none	Both versus none	Both versus STI	Both versus DUI	STI versus DUI
Technological innovations	Eco product	0.064*** (0.024)	0.014 (0.020)	0.191*** (0.019)	0.140*** (0.024)	0.204*** (0.017)	0.047** (0.022)
	Eco process	−0.008 (0.025)	0.091*** (0.021)	0.131*** (0.020)	0.138*** (0.024)	0.032* (0.017)	−0.098*** (0.022)
Non-technological innovations	Eco organisational	0.004 (0.020)	0.073*** (0.018)	0.191*** (0.017)	0.109*** (0.021)	0.033** (0.016)	−0.069*** (0.018)
	Eco marketing	0.005 (0.012)	0.029*** (0.011)	0.082*** (0.011)	0.083*** (0.015)	0.051*** (0.012)	−0.024** (0.011)

Notes: Robust standard errors in parentheses. ****p < 0.01; **p < 0.05; *p < 0.10.*

[a] We report two types of diagnostics regarding matching quality of our estimator. First, Figure A1 in Appendix shows that, in matched data, standardised differences between coefficients are close to zero and weighted variance ratios are close to one, which indicates an optimal matching quality (see also Stojcic, 2021). Second, the overlap plots, reported in Figures A2 and A3 for the full sample and SMEs respectively, reveal that the predicted probabilities are not concentrated near 0 or 1, which implies that the overlap assumption discussed in Section 3.5 is not violated (Cattaneo et al., 2013). We do not show industry and country dummies as the figures would be rather large, but are available upon request.

Table 10
Estimation results from the IPWRA estimator – SMEs (N = 5580).

Types of innovation		STI vs none	DUI vs none	Both versus none	Both versus STI	Both versus DUI	STI versus DUI
Technological innovations	Eco product	0.088*** (0.026)	0.033 (0.022)	0.201*** (0.021)	0.121*** (0.026)	0.191*** (0.018)	0.052** (0.024)
	Eco process	−0.014 (0.027)	0.086*** (0.023)	0.122*** (0.023)	0.130*** (0.027)	0.032* (0.019)	−0.102*** (0.025)
Non-technological innovations	Eco organisational	−0.010 (0.021)	0.067*** (0.019)	0.106*** (0.019)	0.123*** (0.021)	0.026 (0.017)	−0.078*** (0.019)
	Eco marketing	0.007 (0.012)	0.039*** (0.011)	0.085*** (0.011)	0.091*** (0.015)	0.047*** (0.012)	−0.032** (0.013)

Notes: Robust standard errors in parentheses. ****p < 0.01; **p < 0.05; *p < 0.10.*

SMEs.

5.2. Policy implications and further research steps

These outcomes are useful for policymakers as they are informed about the dual possibility to promote eco-innovations, not just through expensive and large firm-led R&D activities and long-term collaborations with universities that demand human resource time, but also through supply chain interactions orientated for instance to apply certified practices (e.g. ISO14,000), strategic collaborations with buyers, and effective internal practices (e.g. teamwork, in-house training). This finding is particularly important for SMEs that for 22% of the cases do not implement any innovation mode/strategy and in 31% of the cases rely only on practice and interaction-based activities. This implies that many firms and SMEs do still leave innovation as a casual outcome of their production activities rather than as the fruit of a systematic approach. Policy makers could take this information as a basis to stir a more proactive and complete approach (the combined STI&DUI)) across firms, in particular by signaling with more evidence the existence of innovation programs focused on SMEs (e.g. Horizon-Europe). This approach could be strengthened also by signaling the positive market response to firms that systematically invest in innovation activities to boost their competitiveness. This implies that policy initiatives at both national and local level can focus on the development of internal activities (e.g. towards the promotion of on-the-job training, teamwork and design) and external activities (e.g. ISO and other relevant certifications, CSR accreditations, as well as marketing and commercial training) that are likely to activate channels that sensitize SMEs towards the request of their end users.

Simultaneously, it is important to recognize the yet limited commitment of SMEs towards eco-innovation in general as only 50% of these firms produce effective process eco-innovations while much lower percentages produce product (37%), organizational (24%) and commercial (11%) eco-innovations. Incentives and sensitization from both public policy bodies and business associations could be put in place to increase the proportion of SMEs that pay attention to this priority for the competitiveness and wellbeing of society.

In conclusion, this is a first analysis on the importance of the archetypical business innovation modes on eco-innovations. Given that the countries in our sample are lagging behind the EU average in terms of innovation performance, findings from this study can be primarily generalized to other European countries at a similar level of innovation performance (e.g. Balkan countries outside of the EU) as well as to countries outside Europe that want to significantly improve their relatively lower innovation performance. Considering the scarcity of empirical findings regarding laggard/catching-up countries, this study might serve as a benchmark.

Moreover, further studies may help deepen this analysis at the micro level; for instance by studying the impact of individual drivers within each of innovation modes (Runst and Thoma, 2021), and at the macro/meso level, for instance through the analysis of the rate of implementation of eco-innovations across different types of countries and regions; e.g. innovation leaders, strong innovators, moderate and modest innovators (Díaz-García et al., 2015; Parrilli et al., 2020), or across industries that are expected to produce a radically different outcome in relation to eco-innovations (e.g. former highly polluting industries such as leather or pulp and paper vs knowledge-intensive business services amongst others). Moving from cross-section type of analysis to panel data would also help to gather the evolution of business innovation modes implemented by SMEs and other firms over time.

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Appendix

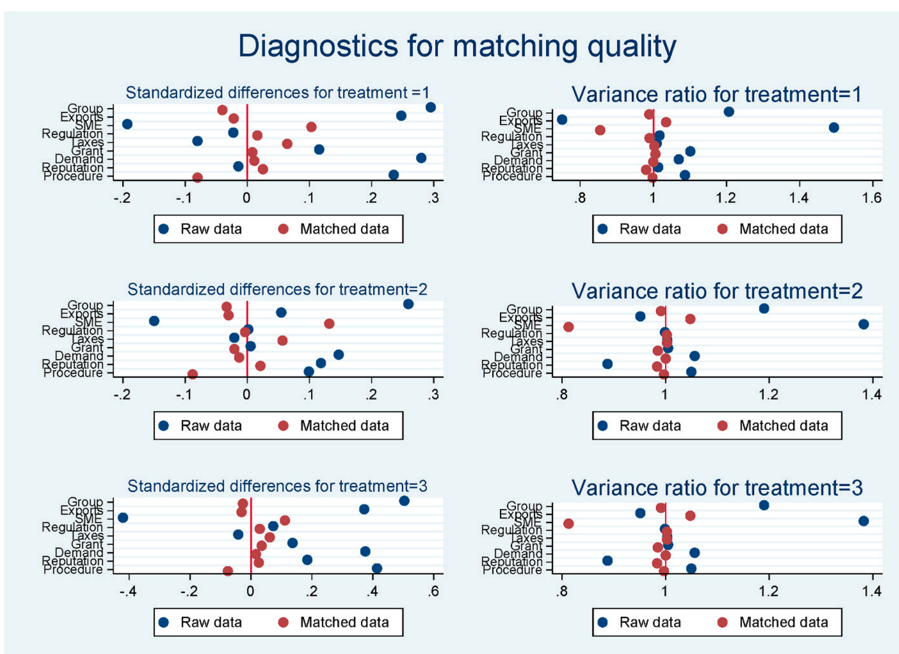

Fig. A1. Covariate balance in the full sample

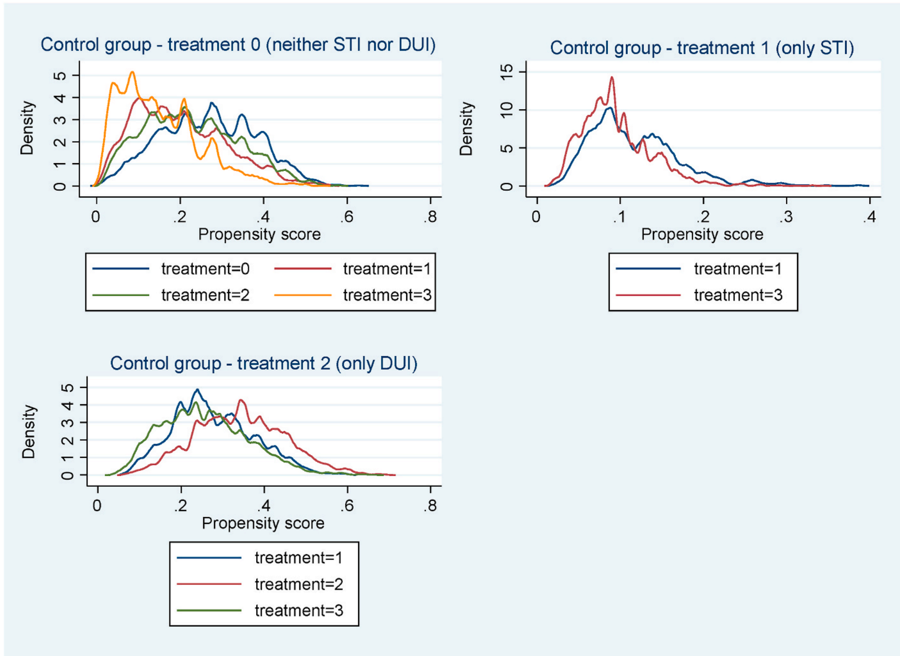

Fig. A2. The overlap plots for the full sample

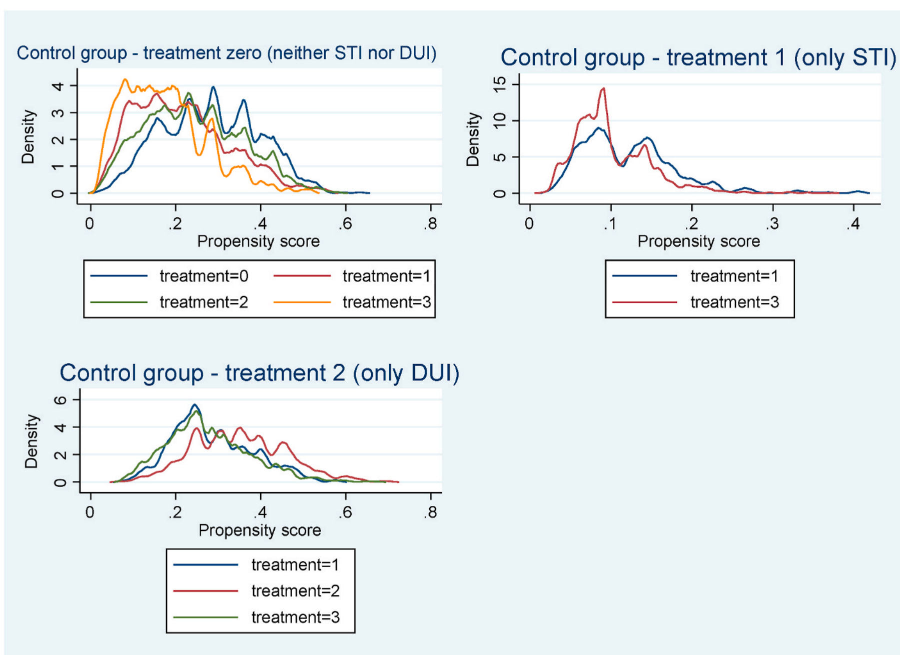

Fig. A3. The overlap plots for SMEs.

Table A1
Robustness check - results from the IPW estimator in the full sample

Types of innovation		STI vs none	DUI vs none	Both versus none	Both versus STI	Both versus DUI	STI versus DUI
Technological innovations	Eco product	0.047* (0.027)	−0.003 (0.025)	0.173*** (0.024)	0.133*** (0.025)	0.205*** (0.017)	0.050** (0.022)
	Eco process	−0.019 (0.027)	0.077*** (0.024)	0.117*** (0.023)	0.130*** (0.026)	0.042** (0.017)	−0.096*** (0.023)
Non-technological innovations	Eco organizational	0.008 (0.020)	0.078*** (0.019)	0.124*** (0.018)	0.109*** (0.022)	0.026 (0.017)	−0.070*** (0.018)
	Eco marketing	0.006 (0.012)	0.032*** (0.011)	0.085*** (0.011)	0.085*** (0.015)	0.045*** (0.013)	−0.026** (0.012)

Notes: Robust standard errors in parentheses. ****p* < 0.01; ***p* < 0.05; **p* < 0.10.*

Table A2
Robustness check - results from the IPW estimator in SMEs

Types of innovation		STI vs none	DUI vs none	Both versus none	Both versus STI	Both versus DUI	STI versus DUI
Technological innovations	Eco product	0.084*** (0.027)	0.032 (0.024)	0.196*** (0.024)	0.117*** (0.028)	0.189*** (0.026)	0.051** (0.024)
	Eco process	−0.014 (0.027)	0.090*** (0.024)	0.123*** (0.023)	0.124*** (0.028)	0.032 (0.019)	−0.104*** (0.025)
Non-technological innovations	Eco organisational	−0.002 (0.021)	0.077*** (0.019)	0.117*** (0.018)	0.118*** (0.024)	0.018 (0.018)	−0.079*** (0.020)
	Eco marketing	0.004 (0.012)	0.038*** (0.011)	0.085*** (0.011)	0.090*** (0.016)	0.045*** (0.014)	−0.033*** (0.013)

Notes: Robust standard errors in parentheses. ****p < 0.01; **p < 0.05; *p < 0.10.*

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