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The impact of environmental research networks on green exports: An analysis of a sample of European countries☆

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A B S T R A C T

This paper studies the impact of environmental research networks on green exports by providing a unique contribution to the studies on the role of collaborative innovation for international competitiveness. Specifically, we adopt the technology gap model of international trade to study the impact of green innovation and the participation in European environmental research programs on green exports for 26 European countries over the period 2003 - 2015. We find that both environmental innovation and research networks positively impact on green exports and that they have a complementary effect that highlights the importance of green absorptive capacity. Moreover, all institutional sectors involved in the networks (firms, universities and public research centers) matter for green competitiveness, with universities playing a major role for institutional complementarities.

1. Introduction

The challenges of the ecological transition are various and complex. They entail different types of international relations: on the one hand, potential conflicts of interests across countries with different economic and social contexts may arise due to different green policies and objectives; on the other hand, there are important potential externalities, economies of scale and economies of scope that can be generated through an efficient green technological cooperation necessary to overcome the large initial costs associated with the ecological transition. In this context the European Union aims to combine environmentally sustainable goals with economic feasibility and competitiveness as well as to relaunch the European economy with new paths of high-tech specialization necessary to maintain and reinforce its international market shares. The European Green Deal, Next Generation EU, Repower EU and Net Zero Industry Act are examples of the European strategy for the green transition. Such a transition can be achieved only through innovation and cooperation among EU members. To this end, the European Commission has been promoting and sustaining initiatives of cooperation in research and innovation, the multi-annual and multi-thematic Framework Programmes (FP), involving all institutional research sectors: firms, universities and public research centers. The core of this strategy is to generate new knowledge and implement it in the business practices and production processes in order to improve the performances of firms and make them more competitive in the global market.

While there is substantial literature studying the impact of FPs on innovation and growth in Europe (Caloghirou et al., 2001; Rodrìguez et al., 2013; Barajas et al., 2012; Di Cagno et al., 2016; Fabrizi et al., 2016; Fabrizi et al., 2018; Amoroso et al., 2018; Nepelski and Van Roy, 2021; Szücs, 2018), there is no evidence of their contribution to green competitiveness and of the specific role of cooperation among different institutional sectors. In this paper we aim to fill this gap by adopting the technology gap approach to international competitiveness (Soete, 1981; Dosi et al., 1990; Laursen and Meliciani, 2000; 2010) and the literature on ecological macroeconomics and catching up in green technologies (Espagne et al., 2023; Althouse et al., 2020; Galindo et al., 2020) in the framework of collaborative innovation (Ghisetti et al., 2015) to test the impact of participation in environmental European Framework Programs for green exports for 26 European countries over the period 2003–2015. We find three main results supporting the importance of joint initiatives and complementarities for reconciling environmental

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goals with international competitiveness. First, research networks positively impact on green exports. Second, they are complementary to green innovation, pointing to the importance of green absorptive capacity to better benefit from cooperation. Third, all institutional sectors involved in the networks (firms, universities and public research centers) play a positive role for green competitiveness and their joint impact is significantly larger than the single one.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework informing our empirical analysis. Section 3 describes EU green research projects. Section 4 introduces the econometric model and estimation strategy. Section 5 discusses the results and, finally, Section 6 concludes the paper by highlighting the policy implications of our findings.

2. Conceptual framework

The conceptual framework adopted in this paper draws on the idea of collaborative innovation (Etzkowitz and Leydesdorff 2000; Ghisetti et al., 2015; Fabrizi et al., 2018) and relates it to green international competitiveness in the framework of the technology gap approach to trade (Soete, 1981; Dosi et al., 1990; Laursen and Meliciani, 2000; 2002; 2010; Dosi et al., 2015).

This approach, originating from the seminal work of Posner (1961), argues that one of the main sources of trade (absolute) advantage of a country comes from its relative technological position against its competitors in any one activity rather than from intersectoral opportunity costs within the same country. In such a perspective, trade flows are primarily driven by technological asymmetries between countries, sectors and firms, which lead to the introduction of new products and processes driving increases in export market shares that relate in first instance to the capability of some countries to produce innovative commodities (i.e. commodities which other countries are not yet capable of producing, irrespective of relative costs) and to use process innovations more efficiently or more quickly, thus reducing input coefficients. Some of these aspects have been formalized by Krugman (1985), Verspagen (1993), Dosi and Nelson (1994) and empirically tested (Soete, 1981; Dosi et al., 1990; Amendola et al., 1993; Laursen and Meliciani, 2000; 2002; 2010; Dosi et al., 2015). In this perspective, the theoretical contributions of ecological macroeconomics (Espagne et al., 2023) consider green technologies and green innovations as an important channel for stimulating international competitiveness: on one hand, green technological progress through the reduction of unit energy and/or raw material costs and in turn the devaluation of real exchange rate can reinforce the price competitiveness in the global market (Galindo et al., 2020); on the other hand, an implementation of ecological transition based on technological progress and sectoral changes (from brown to green sectors) can rise the non-price competitiveness by positively influencing the income elasticity of exports (Guarini and Porcile, 2016; Dávila-Fernández and Sordi, 2020). These streams of literature are taken into account in our empirical model through the direct link between green innovation (measured through green patents) and green international competitiveness (measured by green exports).

However, in order to better account for the sources of green competitiveness, it is important to take into account the peculiarities of green innovation with respect to standard innovation. The knowledge required for the implementation of clean technologies is more complex (Barbieri et al., 2020) and more "codified" than that required for standard innovations (Cainelli et al., 2015) and environmental innovations require more heterogeneous sources of knowledge with respect to other innovations (Horbach et al., 2013). This leads to the importance of collaborative innovation particularly in the case of green innovation (Ghisetti et al., 2015; Fabrizi et al., 2018). The eco-open innovation with a heterogeneity of partners is fundamental because ecological transition requires diversified knowledge that can be produced by interorganizational learning (Albort-Morant et al., 2016). Empirical analyses have supported this view: environmentally innovative firms cooperate on innovation with external partners to a greater extent than other innovative firms (De Marchi, 2012; De Marchi and Grandinetti, 2013; Cainelli et al., 2015) and the breadth of the firm's knowledge sourcing has a positive effect on environmental innovation (Ghisetti at al., 2015).

In the context of green innovation, the interaction and hybridisation between three institutional spheres: 'industry', 'university' and 'government' (Triple Helix, Etzkowitz and Leydesdorff, 2000) in a innovation system approach (Ranga and Etzkowitz, 2013) is particularly important due to the heterogeneity of knowledge required for finding green solutions, the role of regulation in directing green efforts and the necessity of adopting a systemic approach.

According to the empirical and theoretical literature (OECD 2002; Miotti and Sachwald, 2003; Laursen and Salter, 2004; Jaumotte and Nigel Pain, 2005; Paier and Scherngell, 2011), the above-mentioned subjects may draw benefits from their participation in common projects due to access to complementary skills, the reduction of the degree of uncertainty inherent in the cognitive process, the opportunity to move towards the technological frontier, the access to larger financial resources. While inter-institutional cooperation may also give rise to difficulties due to the different types of knowledge and objectives inherent to private firms, public research centres and universities (Foray and Lissoni, 2010), in the case of green innovation the benefits of collaboration are expected to overcome the costs.

For instance, with the green collaboration of the public research sector and universities, firms can develop explorative learning mainly concerning scientific fields and advanced technologies (Miotti and Sachwald, 2003; De Silva and Rossi, 2018) and their creativity can be stimulated (Cainelli et al., 2015).

To capture collaboration, in this paper we focus on environmentally related European Framework Programmes (FP), one specific type of networks involving partners from different countries and different institutional sectors including businesses, universities and research organisations from different EU countries. These Programmes

Finally, we allow for the complementarity between domestic (green innovation) and external (green collaborations) innovation sources drawing on the concept of green absorptive capacity. Absorptive capacity is defined as "the ability of a firm to recognize the value of new external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). At the macroeconomic level, absorptive capacity enables the countries to transform the external knowledge, generated by international research cooperation, into improvements of their international competitiveness. Thus, absorptive capacity can be crucial for countries that are extremely dependent on external knowledge transfer (Lundvall et al., 2009).

Given the higher complexity of green innovations with respect to standard innovations, the concept of green absorptive capacity has been defined as "the capability to identify, assimilate, and exploit external green or environmental knowledge, referred to green knowledge" (Galbreath, 2017). According to Lane et al. (2006), green absorptive capacity is composed of three important learning dimensions: the *explanatory learning* system for identifying novel external knowledge and establishing green innovation standards and environmental legitimacy; the *transformative learning* process for assimilating, using and converting the acquired new green knowledge in green innovations; the *applicative learning* to exploit the abovementioned knowledge for commercialization. All these three learning processes, conceived mainly at microeconomic level (Cui et al., 2021), can be generalized at the macroeconomic level with countries' capability to assimilate external knowledge depending on their internal innovation capacity (Catellacci and Natera, 2013; Fabrizi et al., 2016). In the empirical model, we test for this effect by allowing for the interaction between domestic green patents and green collaborative research in FPs.

We contribute to the literature in several respects. First, this is the first paper relating collaborative green networks (proxied by cooperation in FPs) to green export competitiveness. Second, thanks to the information on the institutional sectors participating in European research networks, we also explore the single and joint impact of firms, universities and public research centres, which allows us to draw implications on the existence of different types of complementarities. Third, we combine data on participation in FPs with data on green patents to investigate the relative importance of green domestic innovation and green international cooperation for environmental competitiveness and to test for the existence of complementarities associated with domestic absorptive capacity.

3. The EU green research networks

Data on joint research projects are drawn from the multi-annual and multi-thematic Framework Programmes (FPs) for Research and Innovation promoted by the European Commission (EC). The FPs started in 1984. From the first year to 2020 there were 8 FPs: until 2007 (FP1-FP6) with a four-year duration; from 2013 (FP7 and FP8) the duration changed to seven years in line with the EU's long-term budget. Currently, the Horizon Europe Programme (2021 – 2027) is in course. Over time FPs have grown in size, becoming one of the largest transnational projects that aim to stimulate research collaborations and disseminate knowledge in the European Union. A key objective of the EU Framework Programmes for Research and Innovation is the creation of cross-country (Balland et al., 2019) and cross-region (Di Cagno et al., 2021) research networks and, a micro-level, between firms, research center and universities (Szücs, 2018).[1]

From a managerial point of view, the FPs include both direct and indirect actions: direct actions are implemented by research institutes directly depending on the European Commission (such as the Joint Research Centre) and indirect actions are carried out through co-financed projects proposed and implemented by entities belonging to the Member States of the European Union and third countries (associated non-EU countries). These participating subjects can be traced back to three macro-sectors: the business sector (or industrial or non-public for profit, BES), the higher education sector (HES) and the public research sector (which we define as the public sector, PUB). This last category includes public for profit, public non-profit actors and other participants (see Fabrizi et al., 2016 and 2018). As mentioned, effective participation in FPs is the result of a complex mechanism involving the decisions of potential participants and the European Commission. During the phase of implementation of FPs, specific calls for proposals are published by the European Commission. Participants must first decide to present a research project, drafting a proposal and identifying research partners. The EC supported by a panel of experts then decides whether finance (part of) the project (Di Cagno et al., 2014; Aguiar and Gagnepain, 2017).

Regarding FPs projects related to the environment-related objectives, as clarified by the European Commission (European Commission 2010) "The Framework Programmes have included environmental issues since the 1980s but the environmental research programme gained substantial momentum from the 1990s onwards" (see also European Commission. 2008).

Environmentally-related (or green) research networks are constructed using EU open data.[2] Our data are related to projects that have green aspects In particular, we use the following FPs/programmes/thematic priority (years)[3]: FP5-EESD (1998–2002),[4] FP6-SUSTDEV (2002 – 2006),[5] FP7-ENERGY, FP7-ENVIRONMENT, FP7-TRANSPORT (2007 – 2013).[6] As in Fabrizi et al. (2018), our choice of these programmes is based on two characteristics: 1) they are strongly related to the environmental goal; 2) they stress the importance of technological development in achieving environmental goals (see also Fabrizi et al., 2018).

Considering that the article's unit of analysis is at the macro level, to build our network variable relating to the environment (*EnvNET*) we have aggregated the data at the country level, starting from the single selected collaborative FPs projects.[7] We then used the project start date as the imputation year to construct our panel data.[8] As mentioned above, the available data allowed us to disaggregate our environmental network variable with respect to the three institutional sectors to which the individual participants belong (*EnvNET_BES, EnvNET_PUB* and *EnvNET_HES*). In Fig. 1, we report for the sample of countries[9] the average number of participants in environmental projects in the period 2003–2014. The Table A.1 in the appendix shows, for each country, the mean number of participated research projects, the mean number of participants (total and disentangled by institutional sectors) and the

[1] This is one of the key principles of the European Union's action, formally expressed in article 179 of the Lisbon Treaty (consolidated version) which reads: "*The Union shall have the objective of strengthening its scientific and technological bases by achieving a European research area in which researchers, scientific knowledge and technology circulate freely, and encouraging it to become more competitive, including in its industry…*" and article 180 which reads "*the Union shall carry out the following activities, complementing the activities carried out in the Member States: (a) implementation of research, technological development and demonstration programmes, by promoting cooperation with and between undertakings, research centres and universities;…*".

[2] Available at https://data.europa.eu/en. For each FPs it is possible to download two files containing one the data relating to the participants (among other things, the project identifier, the name of the organization, the country of residence and the institutional sector to which they belong) and a second with the data relating to the project (among other things, the project identifier, the reference programme/theme and the starting year). From the second file we selected the green projects and associated them with the data of the participants, manually filling in any data missing.

[3] Starting from FP5, the European Commission changes its approach: "*Community research had so far been based largely on technical achievement and that 'the aim now is to make research more efficient and increasingly directed towards meeting basic social and economic needs*"…" *The Commission proposed three thematic programmes under the first activity, shaped no longer as topics but as challenges: unlocking the resources of the living world and the ecosystem; creating a user-friendly information society; and promoting competitive and sustainable growth*" (European Parliamentary Research Service, 2017, pp. 14-15).

[4] FP5-EESD: Programme for research, technological development and demonstration on Energy, Environment and Sustainable Development, 1998-2002 (source: Cordis website available at https://cordis.europa.eu/).

[5] FP6-SUSTDEV: Sustainable Development, Global Change and Ecosystems: thematic priority 6 under the Focusing and Integrating Community Research programme 2002-2006 (source: Cordis website available at https://cordis.europa.eu/).

[6] FP7-ENERGY, FP7-ENVIRONMENT, FP7-TRANSPORT : Cooperation Programme – thematic: Energy, Environment and Transport, 2007 – 2013 (source: Cordis website available at https://cordis.europa.eu/).

[7] Starting from the projects, we added up the individual participants, by country, for each starting year, obtaining the gross total number of participants, since a single participant can be involved in several projects.

[8] For FP7, the average environment-related project duration is 1,210 days (approximately 3.3 years), compared to 1,189 days for the average of all projects (approximately 3.2 years). For the same FP7, all but two of the projects considered in our sample (n. 1502) have a start date prior to 2015 (between 2007 to 2014).

[9] The European countries considered are the following: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, the United Kingdom, Iceland, Norway, Switzerland and Turkey. Of these 26 countries, the first 22 are EU members, the last 5 are non-EU countries

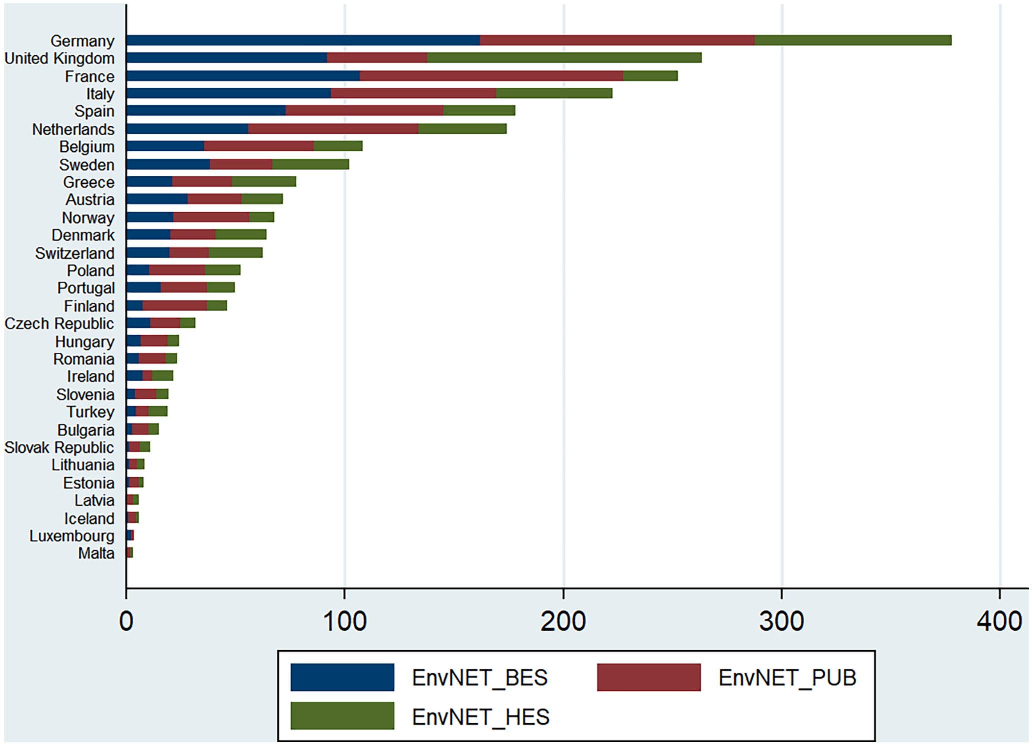

Fig. 1. Mean of FPs environmental projects' participants by institutional sectors (2003 – 2014).
Source: our elaborations on FPs open data

mean number of activated collaborations. As a further variable to describe green research networks, we also add the variable *EnvLinks*, obtained as the sum of the collaboration between country *i* and the other *j*-countries. This measure tell us how many connections a country has and therefore how central it is in the network.[10]

Finally, for the econometric analysis, we standardized our network variables *EnvNET_BES, EnvNET_PUB* and *EnvNET_HES* with respect to the total number of participants in the reference year.

4. Econometric model and strategy

In order to empirically analyze the direct impact of FPs Green programmes on international environmental competitiveness, we estimate an export-gap model (Laursen and Meliciani, 2010) that incorporates green network effects:

$$EnvEXPSH_{itk} = \beta_0 + \beta_1 ULC_{it-1} + \beta_2 INV\_EMP_{it-1} + \ \beta_3 POP_{it-1} + \ \beta_4 \ EXC_{it-1} + \ \beta_5 \ EPAT\_POP_{it-1} \ + \beta_6 EnvNET_{it-1} + + \ \beta_7 \ EPAT\_POP_{it-1} \ x \ EnvNET_{it-1} + \ \beta_8 DNoEU + \gamma_t + v_{it} \quad (1)$$

where, respectively, $i = 1, \ldots,26$ stands for European countries, $t = 2003\ldots, 2015$ refers to years. The countries and time interval of the analysis mostly depend on the availability of OECD data on environmental export goods (until 2016). All variables are expressed in logarithms.

The variable *EnvEXPSH* is environmental (or green) goods export market shares in current USD.[11] The variable *ULC* is unit labor costs expressed as the ratio of total labor compensation per hour worked to output per hour worked; *INV_EMP* is investment per employee; *POP* is population of a given country and *EXCH* is national currency per US dollar; *EPAT_POP* is the green triadic patents intensity [12] *EnvNET* stands for the standardized total number of members of green research networks promoted by the EC. We have added a dummy for non-EU-countries to control the different institutional context. Finally, β_0, γ_t and v_{it} are, respectively, a constant, time dummies and a white noise residual.

According to Steerlink (2005), the variable Environmental (or green) goods export is obtained by aggregating the eleven categories of

[10] In the social network analysis a count of how many social connections (i.e. edges or ties) a node (or vertex) has is called the centrality degree (Borgatti, 2005, Butts, 2008). It is the most basic centrality index to compute. The degree centrality for a node is simply its degree. In our analysis the node is represented by the country: a country with 10 "research" collaborations (connections) would have a degree centrality of 10. A country with 1 edge would have a degree centrality of 1.

[11] The purpose of the empirical analysis is to explain export market shares (absolute advantages) for each country and time period. These are defined as: $EXP_{it}/\sum_{n=1}^{i} EXP_{it}$ but we standardize exports by all countries' average $EXP_{it}/\sum_{n=1}^{i}(EXP_{it})/n$, rather than all the countries' sum to obtain symmetry with the cost variable (where the sum would make no sense). For the same reason, we standardize the other variables in a similar fashion. This is common in the literature (Magnier and Toujas-Bernate, 1994; Amable and Verspagen, 1995; Laursen and Meliciani 2002 and 2010).

[12] We choose the triadic patents as our environmental-related (our green) technological indicator, i.e. patents by priority date, for which applications are filed to three different patent offices: European (EPO), United States (USPTO) and Japanese (JPO). Data are extracted from the OECD PATSTAT (see also Haščič and Migotto, 2015). Although patents have some drawbacks as indicators of technological activity (not all inventions are patented, the incentives to patent differ according to the sector and market, protection systems vary across countries, etc.). Their use as a measure of output of the inventive process has become standard in the literature (Griliches, 1990; Hall et al., 1986). Moreover, the number of patent offices that have protected a given invention is considered a proxy of its economic value and an indicator of the quality of the related patent (Squicciarini et al., 2013).

environmental goods [13] (i) Air pollution control, (ii) Environmental monitoring, analysis and assessment equipment, (iii) Management of solid and hazardous waste and recycling systems, (iv) Noise and vibration abatement, (v) Waste water management and potable water treatment, (vi) Cleaner or more resource efficient technologies and products, (vii) Environmentally preferable products based on end use or disposal characteristics, (viii) Clean up or remediation of soil and water, (ix) Heat and energy management, (x) Natural resources protection and (xi) Renewable energy plant (see also Costantini and Mazzanti, 2012).[14] In Table A.5 we provide a statistic description of export shares for the countries of the sample.

We also study the interaction effects of the type of FPs green participants on international environmental competitiveness:

$$\begin{aligned} EnvEXPSH_{it} = {} & \beta_0 + \beta_1 ULC_{it-1} + \beta_2 INV\_EMP_{it-1} + \beta_3 POP_{it-1} \\ & + \beta_4 EXC_{it-1} + \beta_5 EPAT\_POP_{it-1} + \beta_6 EnvNET_{iBESt-1} \\ & + \beta_7 EnvNET_{iPUB-1} + \beta_8 EnvNET_{iBESt-1} * ENVNET_{iPUBt-1} \\ & + \beta_9 DNoEU + \gamma_t + v_{it} \end{aligned} \tag{2}$$

$$\begin{aligned} EnvEXPSH_{it} = {} & \beta_0 + \beta_1 ULC_{it-1} + \beta_2 INV\_EMP_{it-1} + \beta_3 POP_{it-1} \\ & + \beta_4 EXC_{it-1} + \beta_5 EPAT\_POP_{it-1} + \beta_6 EnvNET_{iPUBt-1} \\ & + \beta_7 EnvNET_{iHES-1} + \beta_8 EnvNET_{iPUBt-1} * ENVNET_{iHESt-1} \\ & + \beta_9 DNoEU + \gamma_t + v_{it} \end{aligned} \tag{3}$$

$$\begin{aligned} EnvEXPSH_{itk} = {} & \beta_0 + \beta_1 ULC_{it-1} + \beta_2 INV\_EMP_{it-1} + \beta_3 POP_{it-1} \\ & + \beta_4 EXC_{it-1} + \beta_5 EPAT\_POP_{it-1} + \beta_6 EnvNET_{iBESt-1} \\ & + \beta_7 EnvNET_{iHES-1} + \beta_8 EnvNET_{iBESt-1} * ENVNET_{iHESt-1} \\ & + \beta_9 DNoEU + \gamma_t + v_{it} \end{aligned} \tag{4}$$

where *BES, PUB* and *HES* stand for the standardized total number of members of green research networks promoted by the EU and, respectively, the total number of Business firms (*BES*), Public research entities (*PUB*) and Universities (*HES*) belonging to these green research networks. Also, in these specifications all the variables are expressed in logarithms.

We use the feasible generalized least squares (GLS) estimator to fit the model. GLS allows us to consider the possible heteroscedasticity and serial correlation in the error term.

5. Results

This section reports the results of the impact of green research networks on international environmental competitiveness as shown in Tables 1 and 2.

To better understand the results, we emphasize that in the model all variables are expressed in relative terms with respect to the average across countries. Moreover, the number of years change in Table 1, given the availability of data. The technology gap export model is generally confirmed both in the original and in the augmented form. Investment per employee *(INV_EMP)* and green patent intensity (*EPAT_POP*) have significant and positive coefficients. Furthermore, price factors are determinants for international competitiveness. On the one hand, the exchange rate (*EXCH*) has a significant and positive coefficient because depreciation facilitates the international price-competitiveness. On the other hand, the unit labor cost (*ULC*) has positive and significant coefficients, representing the so called "Kaldor paradox" (Kaldor, 1978). It could be caused by several factors (Sylos Labini, 1983; Fagerberg, 1988; Dosi et al., 2006; Felipe, 2005): *ULC* can be interpreted as the labor share in output multiplied by a price-adjustment factor, thus its increase could stimulate the growth of a wage-led economy and in turn generate economies of scale positive for exports; *ULC* can capture qualitative elements linked to technology and human capital that in turn increase the non-price competitiveness of exports; *ULC* could spur organizational innovations that raise labor productivity and in turn price-competitiveness of exports; the paradox could reflect the inverse causality between exports and unit labor cost: higher export competitiveness can make increasing wages sustainable. Finally, population (*POP*) represents a control variable without any a priori hypothesis. Thus, the first important finding is that we empirically show the existence of a "green" technology gap export model, opening research fields concerning environmental exports with an evolutionary perspective.

The second interesting finding is that eco-open innovation supported by public initiatives favors international environmental competitiveness: the coefficient of *EnvNET* is significant and positive, confirming the effectiveness of eco-open innovation at international level (Ghisetti et al., 2015) and of international green networks dedicated to technology (Li et al., 2021). This result provides an original multifold contribution: it empirically confirms the Porter Hypothesis in the case of environmental exports, given the fact that the variable concerning networks is a public initiative, namely FPs Green programmes, as well as that it demonstrates that eco-open innovation is valid for international trade, showing an effective channel to develop international environmental cooperation, which sometimes can be complex and ineffective (Sandler, 2016). The statistical relevance of variable *EnvNET* can also approximate the self-feeding interaction between the necessity to comply environmental standards and a fruitful cooperation to overcome potential initial technological barriers (Urpelainen, 2010). Finally, these results confirm at international level the effectiveness of interorganizational learning (Albort-Morant et al., 2016).

The third important finding is the empirical validation of the complementarity between the green knowledge transfer generated by FPs and the green absorptive capacity: the coefficient of the interaction term *EPAT_POP x EnvNET* is significant and positive. The green knowledge transfer by international green networks is transformed into international environmental competitiveness thanks to the green absorptive capacity represented by the environmental patent intensity. This macroeconomic result contributes in an original manner to the literature on the green absorptive capacity that is mainly focused on microeconomic level Galbreath, 2017). According to columns 4 and 5 in Table 1, all the above-mentioned results are confirmed in the medium and long term, providing their robustness. Moreover, Table A.6 in the Appendix strengthens these results by substituting in the Eq. (1) variable *EPAT_POP* with *PAT_POP* (columns 1 −3) and *RD_GDP* (columns 4 – 6) that stand, respectively, for total patents intensity and the R&D on GDP (R&D intensity): these last two variables- that represent an output-oriented measure and an input-oriented measure, respectively- can capture the absorptive capacity of the country. Finally, the results reported in Table A.7 of the Appendix confirm results by substituting in the Eq. (1) variable *EPAT_POP* with *EPO_EPAT_POP*, that is patent applications to the European Patent Office by applicants' country of residence[15] over population (column 1), *EnvNET* with variable *EnvLinks* (column 2 and 3), as alternative network variable, and to check country characteristics (fixed effects) introducing dummy variables (column 4)

[13] Source: OECD.Stat (https://stats.oecd.org/Index.aspx?DataSetCode=TRADEENV_IND10).

[14] The *EnvExp* list contains all environment-friendly products and technologies. However, there is no universally accepted one in the literature definition of *EnvEXP*. Originally, in the late 1990s, the list was developed within the WTO for the definition of the regulation of the international trade of these goods. We have chosen the OECD list, which remains the most commonly accepted among those available (on a relative basis) (Zugravu Soilita, 2018).

[15] Source: Eurostat.

Table 1
Environmental goods export market shares and FPs green projects' participants.

	(1) *BASE*	(2) *NET*	(3) *EPAT x NET*	(4) *LAG3*	(5) *LAG5*
ULC	0.714***	0.722***	0.730***	0.730***	0.724***
	(4.12)	(3.68)	(3.81)	(4.26)	(3.89)
INV_EMP	0.798***	0.845***	0.799***	0.551***	0.577***
	(8.94)	(8.45)	(8.03)	(5.95)	(5.72)
POP	0.827***	0.791***	0.814***	0.780***	0.810***
	(27.05)	(22.57)	(24.02)	(22.85)	(22.61)
EXC	0.0831***	0.0855***	0.0878***	0.105***	0.119***
	(3.70)	(4.49)	(5.00)	(6.15)	(5.61)
EPAT_POP	0.0481***	0.0613***	0.528***	0.579***	0.466***
	(4.36)	(4.96)	(4.98)	(5.47)	(4.22)
EnvNET		0.0591**	0.623***	0.741***	0.561***
		(2.28)	(4.71)	(5.45)	(4.09)
EPAT_POP x EnvNET			0.0455***	0.0520***	0.0388***
			(4.41)	(5.00)	(3.61)
Non-EU Countries Dummy	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes
Constant	−10.09***	−9.301***	−3.395*	−1.185	−2.922
	(−8.38)	(−6.72)	(−1.82)	(−0.67)	(−1.49)
Observations	288.000	262.000	262.000	246.000	200.000
Countries	26	26	26	26	26
Years	13	12	12	11	9
R-squared	0.8946	0.9002	0.9106	0.9022	0.8993
Wald test	851.0604	942.0502	1167.986	958.3657	1089.335

Note: t statistics in parentheses. the feasible generalized least squares (GLS) estimator with robust standard errors and AR(1) autocorrelation within panels. *, **, *** indicate 10 %, 5 %, 1 % significance levels. R-squared is calculated as the square of the correlation between the observed response and the predicted response.

Table 2
Environmental goods export market shares and sectoral FPs green projects' participants.

	(1) **BES**	(2) **GOV**	(3) **HES**	(4) **BES x GOV**	(5) **GOV x HES**	(6) **BES x HES**
ULC	0.923***	0.851***	0.944***	0.639***	0.712***	0.711***
	(4.68)	(4.38)	(5.39)	(3.18)	(3.51)	(3.67)
INV_EMP	0.837***	0.888***	0.731***	0.870***	0.850***	0.861***
	(8.07)	(8.70)	(7.55)	(8.59)	(8.27)	(8.49)
POP	0.809***	0.818***	0.821***	0.784***	0.777***	0.760***
	(25.61)	(28.40)	(26.67)	(23.51)	(22.36)	(22.23)
EXC	0.0808***	0.0896***	0.0830***	0.0819***	0.0829***	0.0815***
	(4.56)	(5.51)	(5.21)	(4.06)	(4.38)	(4.22)
EPAT_POP	0.279***	0.475***	0.482***	0.0661***	0.0593***	0.0708***
	(3.13)	(4.76)	(5.60)	(5.47)	(4.92)	(5.59)
EnvNET_BES	0.236**			0.153		0.205*
	(2.39)			(1.48)		(1.81)
EnvNET_GOV		0.507***		0.186*	0.328**	
		(4.33)		(1.70)	(2.42)	
EnvNET_HES			0.474***		0.299**	0.212*
			(5.01)		(2.31)	(1.89)
EPAT_POP x EnvNET_BES	0.0180**					
	(2.28)					
EPAT_POP x EnvNET_GOV		0.0371***				
		(4.12)				
EPAT_POP x EnvNET_HES			0.0352***			
			(4.90)			
EnvNET_BES x EnvNET_GOV				0.0140		
				(1.44)		
EnvNET_GOV x EnvNET_HES					0.0266**	
					(2.24)	
EnvNET_BES x EnvNET_HES						0.0176*
						(1.73)
Non-EU Countries Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−5.850***	−3.726**	−2.476	−8.468***	−6.301***	−7.383***
	(−3.12)	(−2.01)	(−1.48)	(−4.41)	(−3.11)	(−4.01)
Observations	254.000	260.000	260.000	253.000	258.000	252.000
Countries	26	26	26	26	26	25
Years	12	12	12	12	12	12
R-squared	0.9085	0.9106	0.9106	0.8876	0.8923	0.8921
Wald test	1056.138	1215.586	1137.594	888.6458	883.1631	932.8937

Note: t statistics in parentheses. the feasible generalized least squares (GLS) estimator with robust standard errors and AR(1) autocorrelation within panels. *, **, *** indicate 10 %, 5 %, 1 % significance levels. R-squared is calculated as the square of the correlation between the observed response and the predicted response.

and, finally, to check for endogeneity, using a dynamic model and the one-step GMM system (GMM-SYS, column 5) approach developed by Blundell and Bond (1998).[16]

In Table 2 we present the results breaking down the *EnvNET* variable with respect to the contribution of the individual research sectors, *BES, PUB* and *HES*. We consider the effects of individual research sectors and their interaction (pairwise interactions to reduce the multicollinearity problem).

All institutional research sectors participating in the green networks interact positively with the green absorptive capacity to impact on environmental international competitiveness and the interactions across institutional sectors are positive and significant thanks to universities. In the light of Lane et al. (2006), the positive significant “green research complementarities”- shown in the results - can approximate the relevance of institutional heterogeneity for the green absorption of external knowledge entailing different learning processes: probably, universities and public research sector are more effective in exploratory and transformative learning processes, while the business sector is more capable in applicative learning processes. Moreover, for the business sector committed to ecological conversion it is really important to acquire green external knowledge, given the peculiarities of environmental innovations, specifically from sources external to value chains (De Marchi and Grandinetti, 2013), as in the case of universities and the government sector. In particular, firms can implement sustainable practices thanks to research findings carried out by universities (Nave and Franco, 2019). There emerges an important role for academic institutions as an intermediator between private and public sectors and between business and research activities. This finding captures the complexity of environmental innovations and their multidimensional nature. In fact, the institutional interactions express the complementarity for generating new knowledge between different modes of innovations: Science-Technology and Innovation mode (academic context) and Doing-Using-Interacting mode (business context) (Jensen et al., 2007); in this light, United Nations promote international cooperation in green economy with activities in science, technology and innovations (United Nations, 2023). Furthermore, the predominance of universities in the abovementioned complementarities confirms the sophistication of the knowledge-intensive green innovation processes (Cainelli et al., 2015; Sáez-Martínez et al., 2014); for instance in China the success of hydro technologies is mainly influenced by the strong efforts in R&D by the universities (Zhou et al., 2020; Zhou et al., 2021) as well as the linkages with foreign universities were significant for some important Chinese firms in the energy sector to exploit effectively green window opportunities (Fu and Zhang, 2011; Lema and Lema, 2012 Dai et al., 2020; Haakonsson et al., 2020). Finally, this result can also mirror the higher propensity of universities to cooperate at international level (Scherngell and Barber, 2011).

All these findings are in line with the “green window opportunities” literature based on the dynamic interaction across technological, institutional and market factors that can direct latecomer countries to new sustainable development patterns (Lema et al., 2020). Our results confirm the relevance of political governance of green economy that with respect to the other traditional sectors is more characterized by public goods and complementarities between public and private investment, and influenced by social objectives and values, and international agenda (Deleidi et al., 2020).

6. Concluding remarks and policy implications

The results of this paper show the positive impact of green research networks on international environmental competitiveness, confirming the studies about the advantages of eco-open innovation in terms of economic competitiveness. As illustrated in the previous paragraphs, we have considered the role of European green research partnership programs, and of the three institutional sectors involved in them, namely business firms, universities and public research centers within a technology gap export model (Laursen and Meliciani, 2010) applied to green exports, on a group of 26 European Countries during the period 2003-2015. According to the results, green research networks positively impact on environmental exports and they interact positively with the green absorptive capacity, something that is valid also by considering all the institutional sectors involved in these networks: firms, universities and public research centers. Specifically, in this scenario universities become determinant as drivers of complementarities across institutional sectors. The limits of analysis - due to data availability - can be seen as opportunities for the following research based on the new database: to diversify the impact of environmental networks across the two categories of environmental exports concerning namely end-of pipe technologies and cleaner production; to substitute the macroeconomic variables of the base model with variables concerning the environmental exports sector in terms of wages and investments; to enlarge the list of countries with other green research cooperation initiatives around the world for testing the international heterogeneity of eco-open innovations; to disaggregate the green research partnerships by enterprise dimensions (small, medium, large), technological categories (low, medium high technological intensity) and traditional sectors. The policy implications are multiple: at international level the achievement of SDGs is strictly linked to the implementation of green technological cooperation that permits to generate a win-win strategy with improvements in terms of both environmental sustainability and international competitiveness; indeed, the Commission on Science and Technology for Development of United Nations indicates to reinforce international linkages and networks to create partnerships for producing and diffusing green technologies and implement clean production systems mainly in latecomer countries (United Nations, 2023). At national level, governments should support the international cooperation activities of universities because they generate important spillovers for business and government sectors with a trickle-down effect on the country’s green international competitiveness; in this direction should be supported programs in which universities attract foreign talents (United Nations, 2023) Finally, the impact of green networks on green exports cannot be studied without alerting about the potential rebound effects: on one hand environmental exports can reduce pollution because they contribute to green innovations and in turn to the increases of environmental efficiency; on the other hand environmental exports can increase pollution due to the Keynesian trade multiplier stimulated by the environmental exports; the final net impact on pollution will depend on the matching/mismatching between “green” Schumpeterian and Keynesian forces and mechanisms. Thus, will be fundamental the macroeconomic governance of national and international institutions through the implementation of appropriate initiatives and policies (Guarini and Porcile, 2016).

[16] In the dynamic model, the lagged dependent variable and all the explanatory variables, except *population* (POP) were cautiously considered as being potentially endogenous. We use three (or more) covariate lags as instruments for the endogenous variables. Our choice of instruments was as parsimonious as possible (Roodman, 2009), once the outcomes of autocorrelation tests AR((1) and AR (2).

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Data availability

Data will be made available on request.

Appendix A

Table A.1, Table A.2, Table A.3, Table A.4, Table A.5, Table A.6, Table A.7

Table A.1
FPs green projects (mean value 2003 – 2014).

Country	Green projects	Total participants	Total BES participants	Total GOV participants	Total HES participants	EnvLinks
Austria	48	73	28	25	19	366
Belgium	80	132	36	50	23	578
Bulgaria	13	16	3	8	5	123
Czech Republic	26	32	11	13	7	225
Denmark	40	65	20	21	23	325
Estonia	8	9	1	4	2	83
Finland	30	47	8	30	9	261
France	111	262	107	120	25	758
Germany	144	382	162	126	90	917
Greece	52	79	21	27	29	403
Hungary	20	24	7	12	5	175
Iceland	5	6	1	4	1	45
Ireland	16	22	8	5	10	147
Italy	102	227	94	76	53	702
Latvia	6	6	1	3	3	58
Lithuania	8	9	1	4	4	83
Luxembourg	4	4	2	2	0	28
Malta	4	3	1	1	1	32
Netherlands	92	177	56	78	40	661
Norway	40	69	22	35	12	323
Poland	41	53	11	26	16	340
Portugal	34	51	16	21	13	277
Romania	19	24	6	12	5	168
Slovak Republic	11	11	2	4	5	94
Slovenia	14	19	4	10	5	123
Spain	93	185	73	72	33	648
Sweden	62	102	38	29	35	474
Switzerland	44	64	20	18	25	331
Turkey	15	19	5	6	9	140
United Kingdom	118	269	92	46	126	795

Table A.2
Description of variables.

Variable	Definition	Source
EnvEXPSH	Export share in Environmentally Related Good, total value, current USD (Pollution management, cleaner technologies and products and Resources management group medium)	Own elaborations on OECD data
ULC	Unit labor cost share, ratio of total labour compensation per hour worked to output per hour worked	Own elaborations on OECD data
INV_EMP	Share Gross fixed capital formation (US dollar, Constant prices, PPPs, millions) over employment (persons, millions) share	Own elaborations on OECD data
POP	Total population (thousands) share	Own elaborations on OECD data
EXCH	Exchange rates (monthly averages, national currency per US dollar) share	Own elaborations on OECD data
EPAT_POP	Triadic Patent families in environment-related technologies by priority date over population	Own elaborations on OECD data
EnvNET	FPs green projects’ participants on total green projects’ participants	Our own elaborations EU OPEN DATA
EnvNET_BES	FPs green projects’ participants by BES sector on total green projects’ participants	Our own elaborations EU OPEN DATA
EnvNET_PUB	FPs green projects’ participants by PUB sector on total green projects’ participants	Our own elaborations EU OPEN DATA
EnvNET_HES	FPs green projects’ participants by HES sector on total green projects’ participants	Our own elaborations EU OPEN DATA

Table A.3
Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
EnvEXPSH	406	1	1.733374	0.002484	9.496865
ULC	406	1	1.863084	0.002091	9.995097
INV_EMP	406	1	0.63572	0.040822	3.69645
POP	406	1	1.580379	0.002622	9.063842
EXCH	406	1	1.571372	0.002364	8.970025
EPAT_POP	376	1	0.181898	0.370041	1.367402
EnvNET	376	1	0.38961	0.37445	2.846485
EnvNET_BES	420	1	1.243834	0.014899	4.247332
EnvNET_PUB	378	1	3.194985	0.035546	20.02423
EnvNET_HES	404	1	1.175996	0	4.6497

Table A.4
Correlation between variables.

Nr.	Variable	1	2	3	4	5	6	7	8	9	10
1	ENVEXP	1									
2	ULC	0.2042	1								
3	INV_EMP	0.1113	0.1449	1							
4	POP	0.4442	0.4784	0.5112	1						
5	EXCH	0.6981	-0.0129	-0.1291	0.0837	1					
6	EPAT_POP	-0.1091	-0.0348	-0.1702	-0.1814	-0.1541	1				
7	EnvNET	0.8138	0.3081	0.0179	0.4007	0.758	-0.2044	1			
8	EnvNET_BES	0.8155	0.2875	0.0147	0.3784	0.7416	-0.1823	0.9669	1		
9	EnvNET_PUB	0.6668	0.1888	-0.0758	0.328	0.6568	-0.1896	0.8405	0.7757	1	
10	EnvNET_HES	0.7353	0.3071	0.0622	0.3752	0.6721	-0.1852	0.9094	0.8398	0.5956	1

Table A.5
Mean of environmental export of goods market share, (2003 – 2016).

Country	mean	sd	min	Max
Austria	1.006432	0.029261	0.943413	1.057575
Belgium	1.012281	0.079252	0.89683	1.113311
Czech Republic	0.819448	0.126014	0.625766	1.000852
Denmark	0.79391	0.079477	0.660476	0.912766
Estonia	0.06891	0.014557	0.043599	0.088748
Finland	0.459124	0.045619	0.365586	0.538801
France	2.38305	0.250651	2.066038	2.862471
Germany	9.20012	0.17871	8.922946	9.496865
Greece	0.06185	0.004547	0.055563	0.069688
Hungary	0.592533	0.118911	0.440134	0.84221
Iceland	0.003089	0.000485	0.002484	0.004141
Ireland	0.238101	0.038473	0.203352	0.310156
Italy	3.389117	0.167765	3.103637	3.595317
Latvia	0.029004	0.007302	0.014152	0.038778
Lithuania	0.071128	0.018873	0.041339	0.103309
Netherlands	1.27848	0.078119	1.228839	1.540624
Norway	0.318479	0.049748	0.244529	0.422984
Poland	0.791368	0.166486	0.547143	1.058999
Portugal	0.254124	0.03005	0.22153	0.302747
Slovak Republic	0.252112	0.044831	0.186173	0.315355
Slovenia	0.166907	0.010583	0.155057	0.19727
Spain	1.028683	0.065117	0.938343	1.134409
Sweden	0.85877	0.066921	0.76538	0.97482
Switzerland	1.135511	0.060984	1.048952	1.243743
Turkey	0.452469	0.099591	0.278254	0.586768
United Kingdom	2.00053	0.206862	1.82383	2.458094

Table A.6
Robustness analysis with other innovation variables.

	(1) *PAT_POP*	(2) *LAG3*	(3) *LAG5*	(4) *RD_INT*	(5) *LAG3*	(6) *LAG5*
ULC	0.484***	0.353**	0.453***	0.294*	0.274	0.258
	(2.86)	(2.26)	(2.80)	(1.78)	(1.60)	(1.55)

(*continued on next page*)

Table A.6 (*continued*)

	(1) *PAT_POP*	(2) *LAG3*	(3) *LAG5*	(4) *RD_INT*	(5) *LAG3*	(6) *LAG5*
INV_EMP	0.583***	0.402***	0.474***	0.384***	0.268***	0.172**
	(6.73)	(5.29)	(5.78)	(4.31)	(3.04)	(2.07)
POP	0.813***	0.811***	0.815***	0.942***	0.913***	0.924***
	(26.31)	(24.93)	(25.48)	(35.80)	(29.33)	(27.25)
EXC	0.0715***	0.0817***	0.0942***	0.0391*	0.0610**	0.0562*
	(3.42)	(3.20)	(3.55)	(1.69)	(2.35)	(1.71)
ENVNET	0.576***	0.544***	0.573***	0.993***	1.212***	1.228***
	(6.35)	(6.61)	(6.85)	(3.80)	(4.20)	(4.44)
PAT_POP	0.574***	0.565***	0.590***			
	(6.45)	(6.96)	(7.14)			
PAT_POP x ENVNET	0.0509***	0.0493***	0.0522***			
	(6.17)	(6.53)	(6.73)			
RD_INT				1.654***	1.801***	1.810***
				(6.32)	(6.23)	(6.28)
RD_INT x ENVNET				0.0953***	0.117***	0.121***
				(3.68)	(4.10)	(4.43)
Non-EU Countries Dummy	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-4.926***	-5.229***	-4.549***	4.512	6.580**	6.610**
	(-3.37)	(-3.87)	(-3.35)	(1.64)	(2.15)	(2.21)
Observations	305.000	283.000	231.000	215.000	199.000	162.000
Countries	26	26	26	22	22	22
Years	12	11	9	12	11	9
R-squared	0.9197	0.9133	0.9148	0.9384	0.9340	0.9348
Wald test	1165.477	900.8597	1002.641	2567.249	1411.721	979.4284

Note: t statistics in parentheses. the feasible generalized least squares (GLS) estimator with robust standard errors and AR(1) autocorrelation within panels. *, **, *** indicate 10 %, 5 %, 1 % significance levels. R-squared is calculated as the square of the correlation between the observed response and the predicted response.

Table A.7
Robustness analysis with other patents variables, networks variable and estimators

	(1) *EPO Patents*	(2) *LINKS & Triadic patents*	(3) *LINKS & EPO patents*	(4) *GLS, FE with dummy country variables*	(5) *GMM-SYS*
ENVEXP (lag1)					0.991***
					(173.49)
ULC	0.771***	0.853***	0.809***	0.320***	-0.0407
	(4.39)	(4.50)	(4.51)	(3.02)	(-1.21)
INV_EMP	0.691***	0.854***	0.746***	0.196***	-0.0312
	(7.75)	(8.41)	(8.14)	(3.46)	(-1.47)
POP	0.866***	0.804***	0.841***	-2.161***	0.00352
	(30.81)	(24.16)	(31.71)	(-6.27)	(0.50)
EXC	0.0917***	0.0923***	0.0924***	0.0667	0.00674***
	(4.91)	(5.43)	(5.16)	(0.71)	(2.93)
EPO_EPAT_POP	0.464***		0.0814***		
	(5.94)		(4.10)		
EnvNET	0.429***			0.109*	0.0702*
	(4.87)			(1.87)	(1.89)
EPO_EPAT_POP x EnvNET	0.0432***				0.00645**
	(4.74)				(2.03)
EPAT_POP		0.0460***		0.114***	0.0459*
		(2.61)		(2.63)	(1.86)
EnvLINKS		0.275***	0.189**		
		(2.83)	(2.47)		
EPAT_POP x EnvLINKS		0.0183**			
		(2.21)			
EPO_EPAT_POP x EnvLINKS			0.0145**		
			(2.04)		
EPAT_POP x EnvNET				0.0123**	
				(2.36)	
Non-EU Countries Dummy	Yes	Yes	Yes	No	No
Country dummies	No	No	No	Yes	No
Time dummies	Yes	Yes	Yes	Yes	Yes
Constant	-8.367***	-12.58***	-12.12***	9.733***	0.438*
	(-6.92)	(-10.91)	(-11.60)	(3.62)	(1.75)
Observations	293.000	262.000	293.000	262.000	262.000
Countries	26	26	26	26	26
Years	12	12	12	12	12
Wald test	2026.54	1091.919	1611.902	36931.5	
AR1(p-value)					.0108629
AR2(p-value)					.620094

Note: t statistics in parentheses. the feasible generalized least squares (GLS) estimator with robust standard errors and first-order autocorrelation within panels for the equations 1 – 4. Dynamic model and GMM_SYS estimators for Eq. (5). *, **, *** indicate 10%, 5%, 1% significance levels.

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