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Abstract

This paper studies the impact of environmental research networks on green exports by providing a unique contribution to the studies on the role of eco-open 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 2004 - 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.

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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 and Repower EU 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 (Amoroso et al. 2018; Barajas et al., 2012; Caloghirou et al., 2001;Di Cagno et al. 2016; Fabrizi et al., 2018; Fabrizi et al. 2016; Nepelski and Van Roy, 2021; Rodrìguez et al. 2003; 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) in the framework of eco-open 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 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 eco-open innovation (Ghisetti et al, 2015; Fabrizi et al. 2018) and relates it to green international competitiveness by adopting the technology gap approach to trade (Soete, 1981; Dosi at al. 1990; Laursen and Meliciani, 2000; 2002; 2010; Dosi et al. 2015).

2

Starting from the seminal work of Posner (1961), a stream of analyses has been arguing that one of the main sources of (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 ate al. 2015). The empirical analyses have mainly used data on patents and R&D as proxies for technological advantages and on unit labor costs to test their relative importance for export market shares and have found that technological advantages dominate cost advantages as drivers of international competitiveness in line with the technology gap trade theory and in some cases also confirming the Kaldor paradox (1978).

While this approach has been adopted extensively, to the best of our knowledge it has never been applied to investigate the determinants of green international competitiveness. Nevertheless, other studies, mainly in the context of testing the Porter hypothesis (Costantini and Mazzanti, 2012) - about the potential positive impact of green regulation on innovation and competitiveness - have pointed to the importance of innovation for green exports. At the same time, substantial literature has focused on the differences between green and standard innovation, stressing the importance of collaborative innovation particularly in the case of green innovation (Ghisetti et al. 2015; Fabrizi et al. 2018). This literature draws on the idea that environmental innovations require more heterogeneous sources of knowledge with respect to other innovations (Horbach et al., 2013). 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 this paper we focus on environmentally related European Framework Programmes, one specific type of networks involving partners from different countries and different institutional sectors, to assess their role in fostering environmental international competitiveness measured by green exports.

Specifically, we investigate the export impact of green research cooperation through its complementarities with absorptive capacity, disentangling the institutional research sector peculiarities.

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, 128) and it 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, a specific research field has been introduced on the green absorptive capacity - originally conceived for firms, but now we intend to generalize it at national level - namely "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, can be captured also at macroeconomic level by the interaction between patents and FPs: green absorptive capacity can have a mediating effect on interorganizational learning, green knowledge and green innovation (Cui et al., 2021).

Let us specify some complementarities between green absorptive capacity and each institutional research sector. The complementarity between the business sector and green absorptive capacity can be effective thanks to the moderator effect of the latter between organizational factors and green innovations (Zhou et al, 2021). Indeed, the ecological conversion of firms produces radical innovations of products and/or processes that entail important changes in the organization structure in terms of management, tasks and competences. There exists a potential complementarity between green absorptive capacity and the public research sector because this sector can reinforce the absorptive capacity of green external knowledge by stimulating the compliance of green standards and the achievement of SDGs, as well as by promoting the environmental legitimacy of the other actors involved in the green commitment (Crossley et al., 2021), with a consequent international positive impact on green reputation. Universities are complementary to the green absorptive capacity when they provide high-quality and multifaced research activities, indispensable for effectively implementing green innovations that are complex and sophisticated (Cainelli et al. 2015). The eco-open innovation with a heterogeneity of partners is fundamental because ecological transition requires diversified knowledge that can be produced by interorganizational learning, as in the case of FPs (Albort-Morant et al., 2016). 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).

We contribute to the literature in several respects. First, this is the first paper relating eco-open innovation (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 (FP) 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 2013 with a four-year duration, from 2013 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. 2019) and cross-region (Di Cagno et al. 2021) research networks.

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).

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

Environmentally-related (or green) research networks are constructed using EU open data.[4] Our data are related to projects that have green aspects. In particular, we use the following FPs/programmes/thematic priority (years): FP5-EESD (1998 – 2002), FP6-SUSTDEV (2002 – 2006), FP7-ENERGY, FP7-ENVIRONMENT, FP7-TRANSPORT (2007 – 2014). 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. We then used the project start date as the imputation year to construct our panel data.[5] 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 Figure 1, we report for the sample of countries[6] the average number of participants in environmental projects in the period 2003-2014. Finally, we standardized our variable networks with respect to the total number of participants in the reference year.

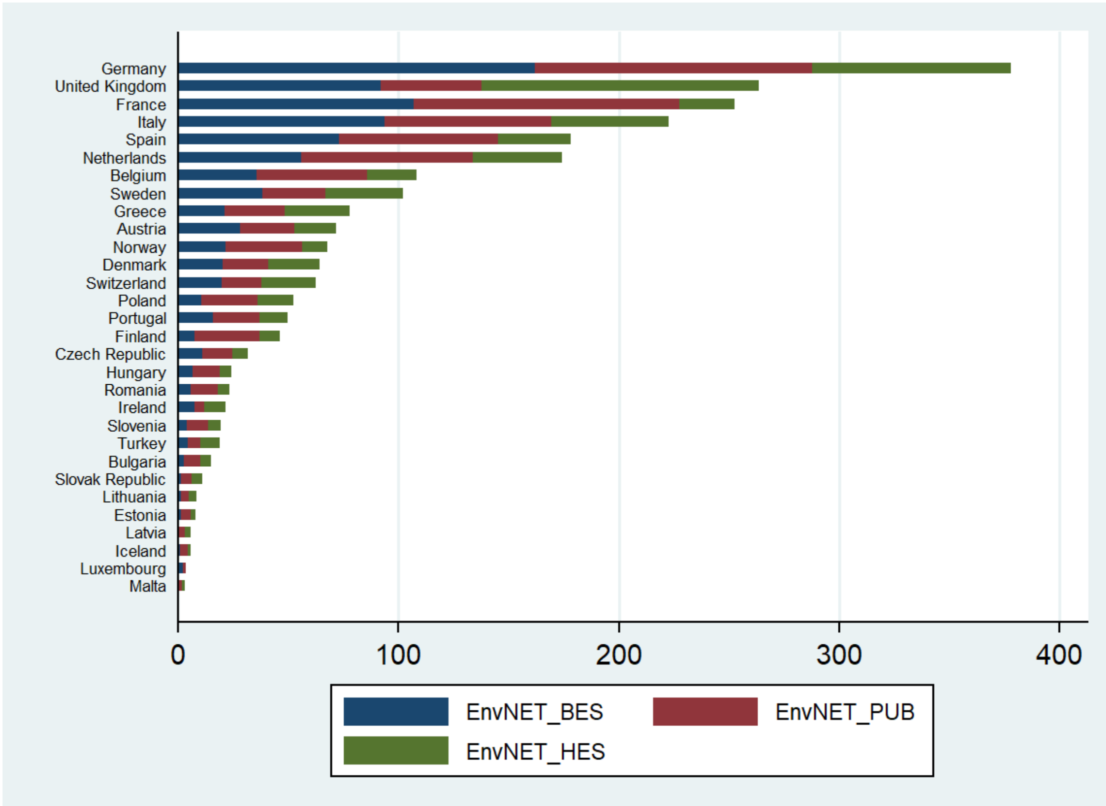
[4] Available at https://data.europa.eu/en

[5] 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).

[6] 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

5

Figure 1: Mean of FPs environmental projects' participants by institutional sectors (2003 – 2014)



Source: our elaborations on FPs open data

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, ...,26 stands for European countries, *t* = 2003..., 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.[7] The variable *ULC* is unit labor costs expressed as the ratio of total labor compensation per hour worked to output per

[7] 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 $EXP_{it}/\sum_{n=1}^{i}(EXP_{it})/$

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;[8] $EnvNET$ 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, $DNoEU$. Finally, β_0, γ_t and υ_{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 environmental goods:[9] (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).[10] 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:

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

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

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

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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).

[8] 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).

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

[10] 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).

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.

Due to the short time dimension of the data, we pool the data over time and 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.

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)	(2)	(3)	(4)	(5)	(6)
	BES	**GOV**	**HES**	**BES x GOV**	**GOV x HES**	**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.

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 Y. 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. Finally, Table A.6 in the Appendix strengthens these results by substituting variable *EPAT_POP* with *PAT_POP* and *RD_GDP* that stand for total patents intensity and the R&D on GDP (R&D intensity), respectively; these last two variables can capture the absorptive capacity.

10

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). Furthermore, the predominance of universities in the abovementioned complementarities confirms the sophistication of the knowledge-intensive green innovation processes (Cainelli et al., 2015). Finally, this result can also mirror the higher propensity of universities to cooperate at international level (Scherngell and Barber, 2011).

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 11 European Countries during the period 2003-2013. 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; 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.

12

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13

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Appendix A

Table A.1: 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.2: 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.3: 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.4: 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

18

Table A.5: 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)
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.