Eco-innovation and exports in heterogeneous firms: Pollution Haven Effect and Porter Hypothesis as competing theories

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Dear Referee 2,

Following your suggestions, we have revised some aspects of the paper as follows:

- Revision of the literature review related to the paper with an improved explanation of the research gap in the Introduction section;
- Revision of the Conclusions section to better highlight the main results (in comparison with the literature), the limitations of the analysis and the insights for future research.

For each part of your suggestions, a detailed answer is supplied.

1. *The review of the literature itself, as a matter of fact, should be improved and the research gap better identified.*

   The Introduction section has been changed from line 42 to line 235, by changing the order of the different strands of literature and highlighting the novelty of our contribution with respect to them.

2. *I would suggest to improve the conclusions in such a way that the main result is evidenced with respect to the literature. Moreover, the limitations of the analysis are not clear and the insights for future research should be further presented.*

   Main results compared with the literature:
   For each result, related to our three theoretical predictions, we have deeply described the connection with the literature:
   a) **Lines 734-746: "*In line with the existing literature, we can assert that results differ by country. In addition to the existing literature, we are able to explicitly identify the driving factors of PHE and strong PH, when exporting decisions are considered. On one hand, the PHE is strictly connected with firms located in less advanced and less innovative European countries (i.e. EE countries). Being a competitive and efficient firm in this area is difficult; the introduction of an environmental regulation reduces the propensity of being competitive, even if a productivity-enhancing effect of environmental innovation exists. Firms should be enough large to achieve a minimum level of competitiveness. On the other hand, more advanced and highly innovative countries, such as Germany, have a socio-economic fabric that constantly supports firms' development. Firms located in these countries are already innovative and prepared to compete on global markets, so they can bear the costs of the implementation of the environmental regulation and advantages, in terms of trade.*"**
   b) **Lines 754-758: "*Through this specific analysis, we have contributed to the existing debate by confirming that the propensity of being an eco-innovator is driven by productivity, and by also giving evidence that this positive relationship is stronger for firms that already innovate, regardless of the type of innovation.*"**
   c) **Lines 762-766: "*With respect to the existing contributions on the relationship between eco-regulation, environmental innovation and trade decisions at micro level, we evaluate the role of export complexity by taking into account the dimension of supplied markets. Moreover, we confirm Bustos (2011) theoretical predictions on innovation, by finding a positive effect of environmental innovation on the propensity of exporting.*"**

Limitations of the analysis:

Work limitations are rewritten as follows:

Lines 789-799: "*From an economic perspective, our work can give important insights into the current EU debate on the relationship among relevant environmental aspects, the role played by firms and their trade decisions. Nevertheless, useful information is missing at firm level and the dataset is cross section in nature. Regarding the available information, we cannot disentangle environmental regulation from eco-innovation adoption and type, so that we partially test our theoretical predictions on PHE and strong PH. With more detailed data on the nature of this variable, a more accurate analysis could be done on how environmental regulation impacts on firms' decisions in the selected sample. Furthermore, information to draw a more precise productivity or TFP variable would be needed. Finally, we cannot give precise insights about intertemporal eco-innovation decisions since the dataset lacks repeated observations over time.*"

Insights for future research:

A further presentation of future research has been done.

Lines 800-820: "***By considering the contribution of our paper and its limitations, further interesting research can be developed. A first extension might distinguish between types of eco-innovation, such as end-of-pipe and cleaner technologies for production, to account for different levels of fixed and variable innovation costs, which may have differentiated effects on firm exporting decisions, as predicted by Bustos (2011). For example, it can be assumed that an end-of-pipe technology requires higher fixed costs only, while the introduction of a cleaner production technology is associated with higher fixed but lower variable costs, than end-of-pipe and dirty-type ones. Moreover, these kinds of eco-innovation can be independently or complementarily adopted by firms, so a study on the joint adoption of these technologies and their drivers can contribute to broaden the research field on the possible mitigation of the environmental burden of production. A second extension could consider the structure of firms. Knowing if a firm is part of an enterprise group, if it is the headquarter and where it is located can provide insights on the geographical distribution and composition of firms in the two European areas. By taking into account these firm characteristics, countries can improve and implement infrastructure management policies to attract foreign firms and to discourage domestic firms to leave the country. Moreover, further investigation on knowledge transfer could be supplied. Finally, given that an EU environmental regulation is usually adopted at different times and through multiple measures at the country level, a quasi-experiment estimation, by means of a difference in difference treatment effect model, could be implemented to tease out the causal relationship among regulation, innovation and trade decisions.*"**

Eco-innovation and exports in heterogeneous firms: Pollution Haven Effect and Porter Hypothesis as competing theories

The effects of environmental policies on eco-innovation and trade performance are studied separately in the literature, and varying inferences across the studies are reported. This paper sheds light on this debate as it theoretically and empirically studies the pollution haven effect and strong Porter hypothesis in a unified framework that accounts for productivity and size heterogeneity at the firm level. The present study discusses a detailed analysis of theoretical predictions and empirical outcomes, based on the regulation–innovation–trade nexus, to assess the specific channels through which such effects might operate. Based on German and East European cross-sectional data at the firm level, results show that an eco-innovation that a regulation induces can generate either a positive effect or a detrimental effect on exporting propensity. Results also suggest that productivity, size and geographical heterogeneity of firms are extremely relevant.

Keywords: Eco-innovation and environmental regulation nexus; Pollution Haven Effect; Porter Hypothesis; Exporting propensity; Firm heterogeneity

Subject classification codes: F18, F23, Q55, Q56

1. Introduction

The international economic and sustainable scenario has become particularly complex and many aspects, such as the environment, innovation, globalization and geography, should be considered. On one hand, public opinion and in particular young people put high pressure on the extreme urgency for climate action and sustainable growth, thus governments are increasingly called to implement environmental policies to reshape production and consumption habits. Moreover, the United Nations Framework Convention on Climate Change encourages the adoption of abatement green innovation in achieving environmental goals in terms of both firms' investments and public authorities' interventions. In a globalized world, firms also face increased market competition and global shocks hit them; thus, internationalization strategies, innovation and environmental issues should not be considered separately. Currently, these actions are increasing in urgency because of the COVID-19 pandemic health crisis and climate change natural disasters on a planetary scale. The resulting economic crisis is deepening and spreading rapidly. On the other hand, it is necessary to consider that European countries invest varying amounts of resources in research and development (R&D) and differences characterize them in terms of technology development and trade openness [Bertarelli and Lodi (2018), Halpern and Muraközy (2012)]. Additionally, they react differently to environmental constraints.

Managing all these interrelated aspects is clearly challenging for firms. Depending on firm-specific characteristics and their location across countries, they will try to manage and adapt to this complexity. Since the early 1990s, this topic has captured many researchers' attention as they have scrutinized the interconnection of firms' features with the imposition of environmental taxation, innovation decision and competitiveness [Tobey (1990), Porter (1991), Porter and Van der Linde (1995)]. Two well-known theories have been developed coherently with this interrelated vision, the Porter hypothesis (PH) and the pollution haven effect (PHE). Evidence suggests that contrasting forces are at work.

This paper contributes to the existing debate on PH (specifically the *strong* version) and PHE by theoretically and empirically assessing the differentiated effects related to both PH and PHE of eco-innovation that an environmental regulation on firms' performance induces. In a world with constant returns to scale, homogenous firms and costless entry, the effects suggested by these two theories cannot coexist together. Differently, adding fixed costs and firms' heterogeneity in terms of productivity reveals different pathways through which innovation induced by environmental regulation can affect firm performance. Specifically, we analyse which firm-specific characteristics and geographical location lead to a positive

impact of regulation-induced environmental innovation on export propensity and which ones are associated with a negative effect. Furthermore, we test if productivity and size heterogeneity influence the propensity of eco-innovating and exporting of manufacturing firms in Germany and East European (EE) countries.

This work can offer relevant contributions to different strands of economic literature.

First, this paper specifically contributes to the literature that analyses the effect of environmental regulations on firms' competitiveness [1]. On one hand, the neoclassical approach asserts that the implementation of a more stringent environmental regulation generates higher compliance costs of production, worsening firms' competitiveness, and increasing outflows of FDI [2], especially in polluting industries [Tobey (1990), Grossman and Krueger (1991), Copeland and Taylor (2004)]. This negative effect, which affects competitiveness, comparative advantage and trade, is well known as PHE, and it has been demonstrated that it entails a decrease of net exports and incoming foreign direct investments for sectors that regulation affects [3]. On the other hand, researchers from the 'competitiveness school' [Mulatu (2018)] demonstrate that environmental regulations represent an important instrument to foster adopting abatement technologies [Milliman and

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[1] **See Mulatu (2018) for a comprehensive review on environmental regulation and international competitiveness.**

[2] A positive connotation also characterizes FDI because they drive the cross-country knowledge diffusion of environmental innovation. The literature has demonstrated that for this specific kind of innovation, knowledge transfer is guided by horizontal linkages (FDI), patenting and joint R&D activities [Gallagher (2014)]. Furthermore, environmental knowledge spillovers are contingent on firms located in nearby countries that already interact and could be connected to vertical linkages. Precisely, if a multinational enterprise adopts an internal policy that fosters environmental technologies adoption, firms integrated into its value chain learn to comply with it as well as if they are located abroad [Ning and Wang (2018)].

[3] **The PHE is a driver of Pollution Haven Hypothesis (PHH), which underlines that trade liberalization can induce a reallocation of production: more polluting industries or firms move toward countries with a less stringent regulation [Copeland and Taylor (2004)]. Despite this work disregards the PHH, it is good to know that the PHE is a necessary, but not sufficient, condition for PHH. It is a sufficient condition when it dominates the other sources of comparative advantage (factor endowments and technological differences) ~~or these sources are absent~~ [Cherniwchan et al. (2016)].**

Prince (1989), Jung et al. (1996), Horbach (2008) and Horbach et al. (2012)], which consequently lead to increased productivity and competitiveness [Porter (1991), Porter and Van Der Linde (1995)]. Particularly, Porter (1991) and Porter and Van Der Linde (1995) formulated the hypothesis that the higher costs related to environmental regulation were paired with improved economic and environmental performance that more advanced (environmental) innovation drove. This assumption is identified with the acronym PH. For the purpose of this paper, we consider only the so-called *strong* PH [Jaffe and Palmer (1997)]. According to this hypothesis, a "well-designed" environmental policy could represent an opportunity for firms: if environmental regulation fostered innovation, it could generate benefits that more than compensate compliance costs and imply an increase in a firm's competitiveness. This mechanism could be socially and economically advantageous. Considering the relationship among environmental regulation, eco-innovation and firms' competitiveness, through our work we can contribute to the literature by theoretically and empirically testing these competing theories concurrently.

Our approach firstly refers to theoretical models that entail firms' trade decisions by allowing for firms' heterogeneity. Several articles have confirmed that international trade patterns, measured as exporting propensity, differ if firms' heterogeneity is considered, in terms of both productivity and size, and for the existence of economies of scale. In his article, Melitz (2003) demonstrated that the most productive firms sell goods to both domestic and foreign markets, while less productive ones supply the domestic market only. Together with productivity, a firm's size has also been recognised as driving competitiveness and market openness. For example, by analysing some evidence on firms' trade behaviour, Bernard and Jensen (1995) and Bernard et al. (2007) discovered that exporters were larger than non-

exporters and different results for small and medium sized firms were registered. The idea that size can be interpreted as an additional measure of firm efficiency can be confirmed. This study provides a formal industry equilibrium model, which accounts for these fundamental aspects to study the trade–innovation–heterogeneity nexus in an environmental context. Moreover, this work takes also into account for the literature that studies the role of innovation in trade decisions. Concerning this aspect, it is commonly asserted that firms' trade decisions are positively affected by innovation adoption [Grossman and Helpman (1991), Yeaple (2005), Piccardo et al. (2016)].

Given the outlined complexity of trade decisions at firm level and our interest in examining the relationship between environmental aspects (regulation and innovation) and exporting propensity of firms, a specific focus is devoted to the strand of literature that generalizes the Melitz (2003) trade model by accounting for, either theoretically or empirically, firms' innovation implementation. According to the pioneering work of Bustos (2011), which was one of the first papers that considered a firm's innovation decision in the Melitz model, a trade liberalization can stimulate upgraded technology adoption. Specifically, Bustos found that, under trade integration, exporters tend to implement technologies that are more advanced. Thus, the most productive firms export and innovate. Other researchers have adopted the same approach to consider a specific type of innovation, namely environmental innovation [Kreickemeier and Ritcher (2014), Cao et al. (2016), Holladay (2016), Cui et al. (2017), Forslid et al. (2018), Qiu et al. (2018), Bertarelli and Lodi (2019) and LaPlue (2019)]. These studies introduce eco-innovation decisions into the Melitz (2003) framework and share that the most productive firms introduce an abatement technology and serve both domestic and foreign markets, while the least productive ones do not innovate, they pollute more

intensively and they serve the domestic market only. From a theoretical point of view, Forslid et al. (2018) introduced an abatement technology mechanism in the same framework and investigated the effect of trade liberalization on an aggregate level of emissions. They showed that trade liberalization increased production and that exporting firms were more likely to invest in abatement technologies to become cleaner than non-exporting ones. Moreover, by adapting Melitz and Ottaviano's (2008) trade model with variable mark-ups, Qiu et al. (2018) examined a monopoly partial equilibrium model and a general economic equilibrium setup, where monopolistic competition was assumed through introducing environmental taxation and innovation investment. They found that only the most efficient firms invested a higher amount of resources in innovation and, even if a tighter regulation caused higher compliance costs, they could obtain a positive effect on competitiveness. Different from these works, which explore the properties of the social optimum of models with investments in abatement technology, export orientation, and emissions, our paper proposes a theoretical framework focused on firms' export status and eco-innovation adoption when a Pigouvian tax is introduced to internalize the environmental externality related to emitted pollution. Firms may decide whether to eco-innovate, and in turn, this decision affects their trade performance.

The above-mentioned frameworks highlight a reallocation market share adjustment that different authors, such as Kreickermeier and Richter (2014), empirically confirmed. They stated that a greater international integration increased productivity at the industry level due to a reallocation effect. This relates to an increase of market shares of the most productive firms at the expense of the least productive ones due to lower trade costs. However, the authors did not evaluate that eco-regulation could imply reallocation effects

per se **due to higher compliance costs because they assumed that they homogeneously hit all active firms. Our theoretical framework fills the gap by including heterogeneous effects of compliance costs to allow for reallocation effects due to eco-regulation and studying the net effect (direct and indirect) of the environmental tax on firms' exporting propensity, which could be either positive or negative, depending on compliance costs, reallocation of market shares and environmental innovation adoption. Moreover, the model considers firms' heterogeneous characteristics (productivity, size and sector), considering they play a crucial role in firms' sorting patterns. This theoretical approach contributes to the existing literature because it allows a joint analysis of all these complex and interconnected aspects. Specifically, according to Cui (2017), we assume that eco-regulation affects production costs in terms of taxes to be paid when firms pollute, but eco-regulation could also induce implementing innovation through adopting advanced abatement technologies of any kind, which are costly and tax saving. These effects are differentiated across firms forcing the most pollutant and least productive firms to exit the market. In turn, reallocation effect implies that emission intensity decreases and productivity increases at the industry level.**

Our formulated theoretical predictions, concerning the effect of environmental regulation, eco-innovation and heterogeneity (productivity and size) relationship on firms' performance, will be empirically tested. Our empirical analysis links to a large strand of the literature concerning the PH and PHE. For the last twenty years, a large number of researchers have empirically studied all versions of the PH[4]**. Concerning the** ***strong*** **PH, results are**

[4] **Other two types of PH have been defined by Jaffe and Palmer (1997). The** ***weak*** **version suggests that command-and-control environmental regulation affects the adoption of "certain types" of innovation, mainly eco-innovation, but they cannot completely offset regulation compliance costs. The** ***narrow*** **PH points out the relevance of more flexible environmental policies, which have a higher impact on the adoption of innovation than command-and-control ones. These regulations also stimulate firms' competitiveness.**

controversial and contrasting, and they depend on different aspects, such as how firms' competitiveness, environmental regulation and environmental innovation are measured. For example, Van Leeuwen and Mohnen (2017) analyzed the effect of environmental regulation, expressed in terms of energy costs, on innovation adoption and productivity, and consequently, on the firms' exporting propensity. They stressed that the strong version of PH, for which eco-regulation can positively affect productivity, is mildly supported, relating the latter to the kind of innovation firms choose. Concerning the PHE, empirical studies commonly agree on the negative effect of environmental regulation on firms' compliance costs [Levison and Taylor (2003), Taylor (2005), Cherniwchan et al. (2017)]. By considering the existing literature and the adopted approach, our work allows us to analyze directly under which conditions the firm-level data supports the PHE or the *strong* PH. By taking into account for the effect of eco-innovation induced by a regulation on export propensity and on the extensive margin of trade with firm-level heterogeneity, we determine whether the least productive firms exit. By assuming that firms can eco-innovate, we open the possibility that eco-regulation can drive firms out of the market when adopting a clean technology of production is unprofitable. A negative (positive) correlation between eco-innovation and export propensity will support the PHE (*strong* PH) hypothesis. Moreover, we have conducted our analysis on two economically and geographically different European areas, such as Germany and EE, by differentiating the firms' propensity of exporting by destination markets. The two specific areas' interconnection drove the choice to study them. On one hand, Germany has an important role for the definition of European Union (EU) policies and represents one of the most advanced (export based) economies in the European scenario. Moreover, it also invests many resources in environmental protection and eco-innovation. On the other hand, EE countries have gained an increasing importance within the EU.

Firstly, they represent a link with West European markets due to their close proximity. They have a geopolitical and geostrategic relevance to achieve political and economic stability in terms of international trade and democracy development. Secondly, EE countries play a relevant role in labour markets; they are endowed with a highly skilled and low-cost labour force, especially in the IT sector [Bertarelli and Lodi (2018)]. These two aspects have brought the West European countries, such as Germany, to invest in EE nations. Nevertheless, this relationship produces advantages for EE countries too; due to knowledge transfer, the countries can fill the gap with the most developed European countries. Besides the strong interconnection between these two areas, the decision to focus the analysis on them is also because they properly represent important benchmarks for different EU countries. For example, all other EU founder countries (Italy, France, the Netherlands, Belgium and Luxembourg), which share common characteristics with Germany, can be classified as advanced EU countries, while other EU members, such as Greece and Portugal, are comparable to EE countries.

By proposing a Melitz-type trade model with environmental taxes, we draw some theoretical predictions. More precisely, a negative direct impact of environmental regulation due to higher compliance costs on exports, and in parallel, a positive direct effect coming from market share reallocation at the sectoral level are shown. An indirect effect is also stated regarding the influence of eco-regulation on innovation, which in turn can affect trade performance. The total effect of regulation on trade performance, which considers the combination of direct and indirect effects through eco-innovation, can be either positive or negative depending on productivity level and the firms' size. Empirically speaking, our paper is innovative because we econometrically test theoretical predictions through the

Endogenous Switching Model. This model is the most suitable for the estimation because our dependent variable (dichotomous) and fundamental endogenous covariate (dichotomous/ordered) are both non-linearly modelled. Moreover, it accounts for data over-dispersion. Considering our aim is devoted to testing the PHE and the *strong* PH at the firm level, the above-mentioned econometric strategy has been applied to the micro data of the 2014 Eurostat Community Innovation Survey (CIS), which also provides comprehensive information about eco-innovation adoption. Precisely, our focus is on German and EE manufacturing firms. Considering EE countries are generally less developed, with respect to Central and West European countries, in terms of innovation investments, environmental sustainability at both the macro and micro level, we can expect different regulation–technology–trade mechanisms.

Furthermore, we have calculated the marginal effects of eco-innovation that regulation induces in a two-equation non-linear system, according to Greene's (1996, 1998) methodology. We use the same approach to measure the direct and indirect (through eco-innovation) effects of productivity and size on export propensity. The computation of marginal effects account for the binary and continuous nature of regressors and for simultaneity bias.

Our empirical results generally confirm that more productive firms have more incentive to eco-innovate and to be exporters. Furthermore, the total effect of an eco-innovation that regulation induces is ambiguous: the *strong* PH is verified for German firms and the PHE is empirically found for EE countries. For German firms, being an eco-innovator that regulation induced increases the propensity of exporting for a given productivity level, while for EE firms, the negative direct effect of the environmental regulation prevails, and the

productivity-enhancing effect of environmental innovation is not enough to bear the higher compliance costs related to the regulation. Furthermore, we can demonstrate that these results are strictly connected to the number of destination markets exporters serve: the adoption of eco-innovation, since an environmental regulation is imposed, positively affects firms' performance when they export to both intra and extra EU countries. This positive effect disappears for exporters that sell in EU markets only. Finally, size and productivity are relevant drivers in explaining the entire nexus among regulation–innovation–trade decisions. Our empirical analysis has been applied on both the sample of all firms- and on a sample of generic innovators, which includes firms that already adopt at least one type of innovation. This robustness analysis follows the idea that more advance and highly innovate firms could enhance their competitiveness when an environmental regulation is introduced. The remainder of the paper is organized as follows. Section 2 provides the description of the theoretical model, while Section 3 proposes the data description and the implemented econometric strategy. Section 4 reports commented results and Section 5 concludes.

2. Theoretical Framework

A theoretical framework, based on Melitz (2003) and Bustos (2011), is developed to allow predictions on the impact of environmental taxation and abatement technology on export propensity at the firm level. The basic framework entails international trade and heterogeneous firms where the manufacturing sector could pollute. Firms should decide whether to invest in abatement technologies and on serving either the domestic market or both the domestic and the foreign markets.

Demand: a constant elasticity of substitution (CES) utility function describes consumers' preferences. Demand for product variety j is expressed as $X_j = Ap_j^{-\varepsilon}$. A denotes the aggregate expenditure for the differentiated product.[5]

Entry and production: each firm produces a differentiated product, which is supplied in a monopolistically competitive market using only one factor of production, labour[6], given an inelastic labour supply, L, at the aggregate level. Considering the adopted technology, firms are heterogeneous in the level of productivity, φ, and draw it from a cumulative probability distribution function, G(φ), when fixed entry costs,[7] f_e, have been paid already. Cost function exhibits constant marginal costs and fixed costs. The latter depends on whether a firm sells to domestic customers or also reaches foreign customers in an imperfectly integrated economy.

Technology: A firm's technology adoption is endogenously drawn. A firm could decide between a dirty (baseline) and a clean (advanced) type of technology. If a firm opts for the first technology, it accepts to emit one unit of pollution for each unit of output for all varieties. For simplicity, we assume that the dirty type technology entails a Pigouvian environmental tax. Otherwise, if a firm adopts a clean technology, it completely abates pollution and does not pay the environmental tax. Because adopting a clean technology requires a high level of R&D investments and new installations on the production process [Kemp (1997)], it asks for higher fixed costs but lower variable costs due to eco-tax saving, compared to a dirty technology [Yeaple (2005)].[8]

[5] It is exogenous at the firm level and endogenous at the industry level.

[6] Nevertheless, firms in the data samples could operate under multiple markets, thus they may implement more factors of production other than labour, such as capital, the database does not collect any information about this input.

[7] They are expressed in units of labour.

[8] Differently from Copeland and Taylor (1994), we have drawn a simplified framework that considers only one factor of production and an exogenous environmental regulation because it is micro-founded. Our simplification allows us to pay more attention to the choice of technology and to analyse firms' differences in terms of innovation.

264 *Firm's decision*: We analyze firm *j's* exporting and technology decisions. A firm can adopt a
265 technology $m = d, c$. Subscripts d and c indicate dirty and clean technologies, respectively. We
266 compare total profits for the alternative technologies when the pricing rule of a fixed mark-up over
267 marginal costs is set. In the presence of CES preferences, we can calculate profits for any non-
268 exporter with an *ex-ante* φ that uses a technology *m*, as follows (*j* subscript suppressed to simplify
269 notation):

$$\pi_m = A\left(\frac{c_m}{\alpha\varphi}\right)^{1-\varepsilon}(1-\alpha) - f_m \quad (1)$$

270 $\alpha = \frac{\varepsilon-1}{\varepsilon}$ is the inverse of the mark-up, while c_m is the marginal cost and f_m are the domestic fixed
271 costs of production. If a firm adopts a dirty technology marginal cost equals $c_d = c(1+t)$;
272 otherwise, marginal cost is c_c. As we can see, marginal cost for dirty firms includes an *ad valorem*
273 environmental tax, t, since pollution cannot be abated. Moreover, considering our theoretical
274 assumptions, $f_c > f_d$.

275 In the presence of variable iceberg trade costs, τ, a firm can get additional variable profits by
276 selling to foreign customers. However, fixed costs of exporting, f_m^*, have to be paid. For any
277 exporter, and for a given *m*, the corresponding profits from export sales equals
278

$$\pi_m^* = A\left(\frac{c_m\tau}{\alpha\varphi}\right)^{1-\varepsilon}(1-\alpha) - f_m^* \quad (2)$$

279 where $\tau > 1$.

280 Following Melitz (2003), we can easily show that the higher the φ, the higher are domestic and
281 export profits. We firstly calculate cut-off productivity levels by imposing zero-profit conditions
282 in (1) and (2). Concerning dirty firms, domestic and foreign cut-offs are obtained as follows:

$$DD = \frac{c(1+t)}{\alpha}\left[\frac{f_d}{A(1-\alpha)}\right]^{\frac{1}{\varepsilon-1}} \quad (3)$$

$$DF = \frac{c(1+t)\tau}{\alpha}\left[\frac{f_d^*}{A(1-\alpha)}\right]^{\frac{1}{\varepsilon-1}} = DD\,\tau\left[\frac{f_d^*}{f_d}\right]^{\frac{1}{\varepsilon-1}} \quad (4)$$

while for clean firms they are they are obtained as

$$CD = \frac{c_c}{\alpha}\left[\frac{f_c}{A(1-\alpha)}\right]^{\frac{1}{\varepsilon-1}} = DD\,\frac{c_c}{c(1+t)}\left[\frac{f_c}{f_d}\right]^{\frac{1}{\varepsilon-1}} \quad (5)$$

$$CF = \frac{c_c\tau}{\alpha}\left[\frac{f_c^*}{A(1-\alpha)}\right]^{\frac{1}{\varepsilon-1}} = CD\,\tau\left[\frac{f_c^*}{f_c}\right]^{\frac{1}{\varepsilon-1}} = DD\,\frac{c_c\tau}{c(1+t)}\left[\frac{f_c^*}{f_d}\right]^{\frac{1}{\varepsilon-1}} \quad (6)$$

By analysing these cut-offs, firms can be classified into three groups for each type of technology: non-active firms, non-exporters, and exporters. The domestic cut-offs, *DD* (*CD*), identifies the lowest productivity levels for successful entry when a dirty (clean) technology is chosen. Analogously, the foreign cut-off, *DF* (*CF*), relates to a dirty (clean) marginal productivity level to get non-negative foreign profits. On one side, a dirty (clean) firm, that produces for the domestic market only will have an ex-ante φ higher than *DD* (*CD*), but lower than *DF* (*CF*). On the other hand, if $\varphi > DF$ ($\varphi > CF$), firms will sell to both domestic and foreign customers. The partitioning of firms will occur whenever $\tau^{\varepsilon-1}\frac{f_m^*}{f_m} > 1$, so that $DF > DD$ ($CF > CD$).

As a final step, we compare the profits of dirty and clean firms to evaluate the firm's technology decisions. We assume that $\frac{f_c}{f_c^*} > \frac{f_d}{f_d^*}$; thus, domestic fixed costs of clean technology are higher than dirty technology, given similar foreign fixed costs. This assumption lets us affirm that exporting firms show a comparative advantage in adopting clean technology than non-exporters; in other words, most productive and exporting firms obtain a higher benefit, in terms of increasing revenues, than non-exporting firms if they decide to implement an advanced technology [Bustos (2011)].

As for the non-exporter, we can show that using clean technology is always dominated by the dirty one when $CD > DD$, which occurs when $(1+t) < \frac{c_c}{c}\left[\frac{f_c}{f_d}\right]^{\frac{1}{\varepsilon-1}} = T1$. When firms export, some of them will use dirty technology, while others will use clean technology. In this case, what is labelled by Bustos (2011) as an adoption productivity cut-off, $\tilde{\varphi}$[9], must be greater than DF. Considering that, the adoption cut-off equals

$$\tilde{\varphi} = DF\left[\frac{f_c+f_c^*-f_d-f_d^*}{(1+\tau^{\varepsilon-1})\left\{\left[\frac{c(1+t)}{c_c}\right]^{\varepsilon-1}-1\right\}f_d^*}\right]^{\frac{1}{\varepsilon-1}} = DD\left[\frac{f_c+f_c^*-f_d-f_d^*}{(1+\tau^{\varepsilon-1})\left\{\left[\frac{c(1+t)}{c_c}\right]^{\varepsilon-1}-1\right\}f_d}\right]^{\frac{1}{\varepsilon-1}} \quad (7)$$

$\tilde{\varphi} > DF$ when $(1+t) < \frac{c_c}{c}\left[1+\frac{f_c+f_c^*-f_d-f_d^*}{(1+\tau^{\varepsilon-1})f_d^*}\right]^{\frac{1}{\varepsilon-1}} = T2$; otherwise, all exporters will adopt the clean technology. When $T1 > T2$, we can obtain three possible scenarios. First, if $(1+t) < T2 < T1$, the environmental tax could guarantee the coexistence of both dirty and clean exporters. A second scenario, that underlines the existence of clean exporters only, is guaranteed if $T2 < (1+t) < T1$. In the third scenario, dirty firms disappear, and both domestic and foreign markets are supplied by clean firms. This is verified when $T1 < (1+t)$.

Industry equilibrium: Two conditions are required to determine the unique industry equilibrium. First, the industry average profit can be calculated by exploiting zero profit conditions (3), (4) and (7) to get a negative relationship between the industry average profit, $\underline{\pi}$, and *DD* as follows:

$$\bar{\pi} = f_d k(DD) + f_d^* k(DF)\frac{1-G(DF)}{1-G(DD)} + (f_c - f_d)k(\tilde{\varphi})\frac{1-G(\tilde{\varphi})}{1-G(DD)} \quad (8)$$

[9] It is obtained by solving the equation $\pi_d + \pi_d^* = \pi_c + \pi_c^*$.

where $k(i) = \frac{i^{1-\varepsilon}}{1-G(i)} \int_i^{+\infty} \varphi^{\varepsilon-1} g(\varphi) d\varphi$, with $k'(i) < 0$ and $i = DD, DF, \tilde{\varphi}$.

Second, a free entry condition must be satisfied; if the net value of entry equals zero, a positive correlation between industry average profit and *DD* exists, which can be drawn as follows:

$$\bar{\pi} = \frac{\delta f_e}{1 - G(DD)} \quad (9)$$

where δ represents a constant probability in every period of a bad shock, related or not to its productivity, that could force a producing firm to exit the market. This exogenous parameter introduces an effect which is quite similar to time discounting [Melitz (2003)].

By combining (8) and (9), a unique domestic cut-off and average profit such that the industry is in equilibrium can be determined. In turn, we can obtain the equilibrium foreign cut-off and the adoption cut-off, from (4) and (7) respectively[10].

The impact of environmental regulation: We have also studied the effect of an increase of t on *DD*, *DF* and $\tilde{\varphi}$. We can show that *DD* and *DF* increase so that it is more difficult to keep producing for the least productive firms, and some low-productive exporters will stop selling abroad. Conversely, $\tilde{\varphi}$ decreases; thus it is convenient for some intermediate productive exporters to switch from dirty to clean technology.

Through this analysis, we have demonstrated that most productive firms invest in abatement technologies and do not emit pollution. Since exporters tend to be more productive and to adopt clean technology than non-exporters, we can state the following predictions to be empirically tested in Section 5:

Prediction 1: The net effect of the environmental tax on the exporting propensity of firms could be either positive or negative. On one hand, a tax directly impacts this competitive measure. There

[10] A detailed analysis of industry equilibrium is reported in Appendix A.

are both negative effects, due to higher compliance costs, and positive ones, related to the reallocation of market shares in favour of surviving firms after the exit of some firms. On the other hand, an indirect positive effect of the eco-tax is also shown since it promotes exporting probability by stimulating environmental innovation. The overall effect is also strictly connected with the distribution of firms by productivity level[11].

By analysing the net effect of the environmental tax on the exporting propensity of firms, we can understand whether the PHE or the *strong* PH is verified. In the former situation, the introduction of a tax is too costly for firms, so it cannot be borne even if an environmental innovation is implemented; benefits from innovation are not sufficient to counterbalance compliance costs, so the exporting probability of firms is negatively affected and PHE will result. Conversely, in the latter situation, a positive net effect happens, and a *strong* PH is obtained.

Prediction 2: More productive firms have a higher propensity to invest in clean-type technologies and to export.

Prediction 3: Since a sorting pattern has been obtained where more productive firms sell in the domestic market and foreign market as well, it can be asserted that the most efficient firms are also bigger in terms of number of employees than less productive and non-exporting ones [Helpman (2006)]. Then, the higher the firm's size, the higher is the propensity of innovating, and the higher is the propensity of being an exporter.

In conclusion, this model can improve our understanding of the *Pollution Haven Effect* and the *Porter* hypothesis by admitting a firms' heterogeneity, in terms of productivity and size, which

[11] For example, assuming a Pareto distribution, positive and negative effects will exactly balance with each other.

may be a driver of the relationships among eco-regulation, eco-innovation and exporting propensity.

The next Section will describe the implemented econometric methodology to empirically test our predictions and data description.

3. Data Description and Econometric Model

3.1 Data Description

Since we aim to evaluate the strong PH and the PHE empirically, for German and EE firms, we need to use a micro level dataset which gives information about firm-level heterogeneous characteristics, environmental innovation and regulation. For this purpose, the Eurostat CIS2014 dataset is most suitable. Specifically, German and East European[12] manufacturing firms' data have been considered. This database reports cross-section observations with reference to the 2012-2014 time period. Firms' performances are measured through the exporting propensity and the effect of eco-innovation induced by regulation on it is estimated. Firms come from different manufacturing sectors classified at *2-digit level* Nace Rev.2[13]. Observations regarding export and innovation induced by regulation entails 2,889 firms for Germany and 18,387 firms for EE countries. Tables from B.3 to B.6 reported in Appendix B show variables' description and summary statistics.

3.2 Eco-innovation induced by environmental regulation

In order to identify the most suitable variable for eco-innovation induced by environmental regulation, some specifications on eco-innovation and eco-regulation are required.

It is well-known that the introduction of an environmental innovation should reduce environmental risk in terms of emitted pollution and/or resources used in the production process. In its 2013 report

[12] The sample of Eastern European countries includes Bulgaria, Croatia, Hungary, Lithuania, Latvia, Romania and Estonia.

[13] See Tables B.1 and B.2 in Appendix B for sector description.

'Eco-innovation: The key to Europe's future competitiveness', the EU, identifies eco-innovation as '*any innovation resulting in significant progress towards the goal of sustainable development, by reducing the impact of our production modes on the environment, enhancing nature's resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources*'. In the CIS dataset, it is specifically defined as a new or significantly improved products (goods or services), process, organisational method (or marketing method) that creates environmental benefits compared to alternatives. For our purpose, eco-innovators are represented by those firms that adopt innovation devoted to the reduction of material or water use per unit of output, the reduction of energy use or CO2 'footprint', decrease of air, water, noise or soil pollution, replacement of materials with less polluting or hazardous substitutes, the replacement of fossil energy with renewable energy sources and/or the recycling of waste, water, or materials for own use or sale. This information is not sufficient to empirically test the strong PH, so we have investigated the role of firms that are fostered to innovate because of the existence of regulations, taxes, charges or fees. Unfortunately, CIS dataset does not allow us to observe eco-regulation independently from eco-innovation adoption and types of eco-innovation. Furthermore, we are not able to identify sector and country specific environmental regulation in order to differentiate regulation level, effectiveness and impact. Given these limitations, we can study the effect of eco-innovation adoption due to the existence of a general environmental tax or charge on firm performance[14].

3.3 Econometric Model

[14] Technically, this measure is originally drawn as an ordered variable, but we transform it into a dichotomous one. Firms can choose among four degrees of importance of the regulation in introducing innovation: 0 not important, 1 low importance, 2 medium importance, 3 high importance. For our analysis, the degree equals 1 if firms answer 1, 2 or 3, and 0 otherwise.

Since export and eco-innovation are binary variables, we deal with the non-linear nature of their relationship and between dependent variables and other regressors[15]. By considering the potential endogeneity of eco-innovation induced by regulation and possible overdispersion of data, we estimate the Endogenous Switching Model (ESM) drawn by Miranda and Rabe-Hescketh (2006). The ESM model is expressed as an equation system of two latent variables. The first equation can be expressed as

$$dEXP_i^* = \alpha_1 dEnvInno_i + \alpha_2 Prod_i + \boldsymbol{\beta Size_i'} + \boldsymbol{\gamma Sector_i'} + u_i \qquad (10)$$

$$dEXP_i = \begin{cases} 1 \; if \; EXP_i^* > 0 \\ 0 \; otherwise \end{cases} \qquad (11)$$

where $dEXP_i$ is the binary variable that identifies i's firm's exporting status[16]. More precisely, a firm's exporting performance equals 1, if a firm exports to European Union (EU) countries and/or to other extra EU countries, 0 otherwise[17]. $dEnvInno_i$ is the dummy related to the implementation of an eco-innovation induced by an environmental regulation. Since it represents a crucial variable, a devoted subsection will follow the description of the empirical strategy. Productivity ($Prod_i$) is also considered as a continuous explanatory variable. Since the dataset does not provide a labor productivity measure, it is calculated in terms of firm's relative profitability, as proposed by Aw et al. (2008). Specifically, this measure is the log of the firm's revenue share expressed as a

[15]The model is similar to a bivariate probit regression, but it differs in terms of variance. In bivariate probit, variances are set to 1, while no specific parameters are identified for these values in the endogenous switching model. Nichols (2011) has demonstrated that the bivariate probit model requires strong parametric assumptions, so it is not suitable if endogeneity of other variables are suspected and it cannot properly manage the overdispersion of data.

[16] Concerning trade performance, as a possible competitiveness measure, several variables have been used and tested in firm level empirical studies. For example, Rammer et al. (2017) contribute by measuring export performance through two variables: exports on total sales at the end of a period and a dummy variable for export activities in the last period.

[17] According to the existing literature on international trade with heterogeneous firms, this variable has been interpreted as economic performance. As generally asserted, international trade propensity is strictly related to productivity at firm level, so only the most productive firms may serve foreign markets.

deviation from the mean log of market share in the 2-digit industry. $Prod_i$ is defined as $\ln\left(\frac{turnover_i}{sector\ turnover}\right) - \frac{1}{n}\sum_i \ln\left(\frac{turnover_i}{sector\ turnover}\right)$, where $turnover_i$ is the turnover of *i* firm in 2014, *n* is the number of firms in a specific sector and $sector\ turnover$ represents the total market size measured in terms of total sector turnover. In the CIS dataset, turnover is defined as total market sales of goods and services (including all taxes except VAT). $\boldsymbol{Size'_i}$ represent a set of three dummies related to firms' classification in terms of number of employees (*dsmall, dmedium* and *dlarge*), and $\boldsymbol{Sector'_i}$ is a set of dummies that refer to Nace sectors[18]; both variables also account for heterogeneity across firms. u_i is the error term. α_1, α_2, β and γ are the parameters to be estimated.

The second equation captures the potential endogeneity of eco-innovation induced by the environmental regulation variable, and it can be represented as follows:

$$dEnvInno_i^* = \delta_1 Prod_i + \boldsymbol{\eta Size'_i} + \Upsilon \boldsymbol{Sector'_i} + \boldsymbol{\theta Z'_i} + v_i \qquad (12)$$

$$dEnvInno_i = \begin{cases} 1 \ \ if\ EnvInno_i^* > 0 \\ \ \ 0\ otherwise \end{cases} \qquad (13)$$

where $\boldsymbol{Z'_i}$ is a set of instrumental variables, v_i is the error term δ_1, η, Υ and θ are the parameters to be estimated. Chosen instrumental variables are confirmed to be strong and exogenous. On one hand, they are strong because they are supported by the existing literature, so by the already empirically identified drivers of eco-innovation (demand-pull factors, technology-push factors, environmental regulation, and firms' characteristics) [Horbach (2008) and Horbach et al. (2012)]. On the other hand, these covariates are exogenous since their causes are external to the model and they are relevant to represent and explain eco-innovation adoption probability; moreover, they do

[18] See Table B.3 in Appendix for detailed variable description.

not affect firms' exporting propensity. By applying tests for instruments identification, we can assert that exclusion restrictions hold[19]; corresponding F-statistics are statistically significant and equal to 29.76 and 46.86 for Germany and EE countries respectively. Relating to German firms, two literature supported instruments are found. The first instrument is a dummy variable that underlines the cooperation arrangements on innovation activities ($CoAll_i$). This variable measures the importance of knowledge sharing and cooperation for the adoption of innovation [Horbach et al. (2012)], especially in multinational firms. The second instrument identifies whether R&D activities are undertaken by, or contracted out to the enterprise to create new knowledge or to solve scientific or technical problems (rd_i). It is globally recognized that R&D investment for the improvements in technological capabilities of firms increases the propensity for being an eco-innovator [Horbach (2008)]. Concerning EE firms, two other empirically valid instruments have been identified. The total expenditure in R&D activities ($rdExp_i$), and the level of reputation of a firm in terms of sustainability and attention to the environment ($Reput_i$) have been considered. On the one side, $rdExp_i$ captures the total amount of expenditure in R&D, acquisition of machinery, equipment, software, buildings, knowledge from other enterprises or organisations, and other relevant activities, such as design, training and marketing. On the other hand, $Reput_i$ is a dummy variable for the existence of procedures to regularly identify and reduce an enterprise's environmental impact, including the preparation of environmental audits, the setting of environmental performance goals, and the acquisition of some certifications (ISO 14001, ISO 50001). As reported in Demirel and Kesidou (2011), certifications strengthen the positive impact of environmental management systems on eco-innovation adoption.

3.4 Econometric Model Assumptions

[19] See Table B.9 and B.10 in Appendix B for detailed results of the instrumental variables test.

448 Probit models are used for both $dEXP_i$ and $dEnvInno_i$. u_i and v_i are assumed to be bivariates 449 normally distributed. Regarding the ESM, potential dependence among u_i and v_i is accounted for 450 by using a shared random effect, ε_i. This means that: $v_i = \varepsilon_i + \varsigma_i$

$$u_i = \lambda\varepsilon_i + \tau_i \quad (14)$$

$$v_i = \varepsilon_i + \varsigma_i \quad (15)$$

451 τ_i, ς_i and ε_i are independently normal distributed random variables with 0 mean and a variance 452 equal to 1. λ, the *factor loading*, represents a free parameter. The covariance matrix of u_i and v_i 453 is:

$$Cov\{(u_i, v_i)'\} = \begin{pmatrix} \lambda^2 + 1 & \lambda \\ \lambda & 2 \end{pmatrix} \quad (16)$$

454 and correlation ρ is given by

$$\rho = \frac{\lambda}{\sqrt{2(\lambda^2 + 1)}} \quad (17)$$

455 The model uses a Generalized Linear Latent and Mixed Model by stacking the response variables 456 into one variable, q_{ik}. It is supposed that q_{ik} has a binomial distribution. *k* equals 1 if q_{ik} refers to 457 the main response $dEXP_i$, but *k* equals 2 if it concerns the switching response $EnvInno_i$. Viewing 458 both response variables as clustered within firms, it may be possible to define two dummies, 459 $d_{1ki} = 1$ if *j=1* and d_{2ki} if *k=2*. The conditional mean of q_{ik} is specified as $E(q_{ik}|\varepsilon_i)$, and the link 460 function for responses q_{ik} is probit and may be defined as:

461

$$g_k[E(q_{ik}|\varepsilon_i)] = d_{1ki}(\alpha_1 dEnvInno_i + \alpha_2 Prod_i + \boldsymbol{\beta Size_i'} + \boldsymbol{\gamma Sector_i'} + \lambda\,\varepsilon_i) + d_{2ki}(\delta_1 Prod_i + \boldsymbol{\eta Size_i'} + \Upsilon \boldsymbol{Sector_i'} + \boldsymbol{\theta\, Z_i'} + \varepsilon_i) \quad (18)$$

The obtained coefficients are estimated by Maximum Simulated Likelihood (MSL) and the unobserved heterogeneity, captured by ε_j, is integrated out into the model.

4. Results

4.1 Exporting propensity, firm's heterogeneity and eco-innovation induced by regulation

By implementing the ESM, we aim at testing the predictions of our theoretical model. Specifically, we will analyse the existence of either the *strong* PH or the PHE, when the competitiveness of a firm measured by its exporting propensity and heterogeneity across firms is taken into account. Estimates are based on equations (10) and (12) and the baseline model (Model 1) for both Germany and EE countries is estimated given *dEXP* and *dEnvInno* as dichotomous dependent variables. The estimation is also made for a sub-sample of innovative firms for Germany and the EE (hereafter generic innovators). More precisely, we consider all firms making at least one of the following kinds of innovation: product, process, organizational/marketing, and environmental. The comparison between the two groups allows us to capture potential differences regarding innovators from the whole sample of firms. Coefficients are reported in Table 1.

Table 1. Exporting propensity, firm's heterogeneity and eco-innovation induced by regulation (Coefficients Estimate, Model 1)

	Germany		East European Countries	
	All sample	*Innovators*	*All sample*	*Innovators*
dEXP				
dEnvInno	0.268*	0.137	-0.215	-0.233
	(0.141)	(0.157)	(0.276)	(0.278)
Prod	0.392***	0.404***	0.256***	0.254***
	(0.039)	(0.042)	(0.033)	(0.032)
dmedium	-0.018	-0.061	0.321***	0.321***
	(0.098)	(0.104)	(0.093)	(0.093)
dlarge	-0.449**.	-0.495**	0.511***	0.516***
	(0.185)	(0.194)	(0.163)	(0.163)
Constant	0.987***	1.021***	0.559**	0.572**
	(0.209)	(0.226)	(0.278)	(0.279)
dEnvInno				
CoAll	0.083	0.072		
	(0.079)	(0.080)		
Rd	0.581***	0.256***		
	(0.087)	(0.094)		
Reput			0.572***	0.567***
			(0.068)	(0.097)
rdExp			0.124	0.116
			(0.114)	(0.112)
Prod	0.098***	0.100***	0.103***	0.102***
	(0.034)	(0.036)	(0.029)	(0.029)
dmedium	0.088	0.050	-0.121	-0.124
	(0.096)	(0.100)	(0.087)	(0.136)
dlarge	0.321*	0.248	-0.151	-0.140
	(0.170)	(0.179)	(0.135)	(0.137)
Constant	-0.996***	-0.642***	0.106	0.110
	(0.221)	(0.233)	(0.201)	(0.201)
N. of Observations	2987	2318	18951	5553
Log Likelihood	-2059.47	-1860.49	-1880.55	-1864.82
Wald Chi2	772.33***	571.59***	439.09***	430.80***

Note: Significance levels: *** 0.01, ** 0.05, * 0.1. Sectors dummies are statistically significant, but they are not reported. They are available upon request. *dsmall* dummy has been omitted due to collinearity.

After a preliminary analysis to test for the possible endogeneity of the regulation-induced environmental innovation and to avoid any potential bias issue, the endogeneity hypotheses and the overdispersion of data cannot be rejected for both German and EE countries' firms.

By a first analysis of coefficients, we can confirm that the eco-innovation induced by environmental regulation has a positive effect on the exporting propensity of German firms. Nevertheless, if we compare Columns 1 and 2 of Table 1, this result is statistically significant for the entire sample only; the existence of an environmental regulation represents an important driver of efficiency and competitiveness, especially for non-innovators. Focusing on EE firms, an opposite result is obtained. Firms are not able to bear the costs related to the introduction of a regulation, even if they innovate; eco-regulation lowers their competitiveness in terms of exporting propensity.

Concerning productivity, Table 1 shows that *Prod* positively and significantly affects both exporting propensity and probability of being an eco-innovator even if an environmental regulation has been introduced. This result is verified for all samples[20].

Furthermore, we can also study the effect of size heterogeneity across firms. This analysis is useful because it could highlight whether firms react differently in terms of exporting and eco-innovation decisions if a regulation is imposed. Firstly, it is possible to assert that, for German firms, a change from being a small to a medium or large firm has a negative effect on the exporting probability of firms; *dlarge* only is statistically significant. This means that being small brings firms to having a higher propensity for being an exporter. This latter result is not in line with the literature; we need to investigate more deeply the relation between size and exporting decisions by studying the corresponding marginal effects. For EE firms, we conversely register a positive and statistically significant impact of a change in size on the probability of being an exporter; being a medium or large firm increases the probability of exporting. Thus, for EE firms, size can be interpreted as an additional measure of the firm's efficiency [Bernard and Jensen (1995), Wagner (1995), Bernard et al. (2007)]. By comparing these two results, it seems that EE firms, with respect to German

[20] The results connected to productivity have been also confirmed by the application of a non-parametric approach. Differences between productivity distributions will be tested through Kolmogorov-Smirnov test and Kruskal-Wallis test.

ones, should be medium or large in order to have a higher market competitiveness, so as to export also to foreign markets.

Moreover, Table 1 shows that size does not a significant effect on the adoption of eco-innovation [Horbach (2008)]. An exception is recorded for Germany regarding all firms' samples; being a small firm decreases the probability of being an eco-innovator when an environmental regulation exists. As pointed out by Khanna (2001) and Hillary (2000), smaller firms could have higher marginal abatement costs than larger ones and fewer employees to meet all requirements; moreover, they have lower financial resources to implement environmental (advanced) innovation activities.

Focusing on the impact of instrumental variables, they all show a positive effect on the propensity of being an eco-innovator because an eco-regulation has been imposed. Specifically, we can assert that, for German manufacturing firms, only *rd* has a statistically significant impact on this probability; while for EE firms, their reputation in terms of attention to environmental issues represents a crucial driver for *dEnvInno*. These positive results are consistent with the existing literature on the drivers of environmental innovation [Frondel et al. (2007), Demirel and Kesidou (2011), Horbach et al. (2012)].

Since the absolute scale of coefficients may give distorted results about the response of the dependent variable to a change in one of the main covariates in nonlinear models [Greene (1998)], the marginal effects of the endogenous dichotomous variable (*dEnvInno*), the continuous variable (*Prod*) and the exogenous binary variable (*Medium/Large Firm*) are respectively calculated by following Greene (1996, 1998). More precisely, for the productivity variable, the total marginal effect is obtained by summing its direct and indirect marginal effects on being an exporter; while considering the change in size, the corresponding marginal effect of being a medium or large firm on export status can be expressed as the sum of its marginal effects related to eco-innovation adoption. A detailed analysis of the computation of marginal effects is reported in Appendix C and the results are reported in Table 2.

Table 2. Exporting propensity, firm's heterogeneity and eco-innovation induced by regulation (Marginal Effects - Model 1)

	Germany		**East European Countries**	
	All samples	*Innovators*	*All samples*	*Innovators*
dEXP				
dEnvInno	0.067**	0.034**	-0.035	-0.038
	(0.032)	(0.016)	(0.025)	(0.027)
Prod				
Direct effect	0.198**	0.199**	0.084	0.083
	(0.093)	(0.096)	(0.059)	(0.058)
Indirect effect	0.028**	0.064***	0.048	0.046
	(0.013)	(0.024)	(0.032)	(0.031)
Total	0.250***	0.254***	0.129*	0.126*
	(0.087)	(0.091)	(0.068)	(0.067)
Medium/Large Firm				
dEnvInno=1	0.026	0.001	0.053	0.056
	(0.048)	(0.052)	(0.050)	(0.050)
dEnvInno=0	-0.117***	-0.105**	0.040	0.037
	(0.039)	(0.042)	(0.032)	(0.031)
Total	-0.091*	-0.103*	0.093*	0.093*
	(0.052)	(0.062)	(0.051)	(0.051)

Note: Significance levels: *** 0.01, ** 0.05, * 0.1

Considering German and EE firms, marginal effect analysis confirms previous estimates. The environmental innovation induced by regulation has a positive and statistically significant effect on the exporting propensity of the samples of both all and innovative German firms. As shown in Columns 1 and 2, introducing an eco-innovation driven by a regulation increases the probability of exporting by 6.7% and 3.4%, respectively. This result underlines that firms can benefit from the introduction of an environmental innovation induced by regulation even if we consider the generic innovators sample. Concerning Prediction 1, our results are in line with the literature that supports the strong PH [Testa et al. (2011), Albrizio et al. (2017), Franco and Marin (2017)]. We consequently infer that the reallocation of the market share effect prevails in the effect of higher compliance costs. Benefits generated by the adoption of eco-innovation more than counterbalance the compliance costs related to environmental regulation, so German manufacturing firms have a higher propensity for being exporters. As reported, if we test our hypothesis on the whole sample of firms, which comprehends innovators and non-innovators, the magnitude of marginal effects is higher and better trade performance is recorded. This result suggests that the net positive effect of environmental regulation is stronger if non-innovators are included in the sample. We can interpret this finding with the idea that firms that already innovate already have competitive position on foreign markets, while non innovators may enjoy larger benefits in term of exporting performance if they eco-innovate. Results for EE firms conversely show negative and non-statistically significant marginal effects of *dEnvInno* (3.5% and 3.8%), which reflects the PHE as the prevailing effect. Firms in less technologically developed EU countries cannot bear the higher costs connected to the regulation, even if a connected eco-innovation is implemented. This does not necessarily mean that EE firms are not eco-innovative. As asserted by Lanoie et al. (2011), since a huge amount of the investments required to comply with regulation represent additional production costs, the net effect still remains negative, although a part of them may be offset by benefits of R&D investment.

Regarding productivity, the marginal effect of a change in *Prod* on the propensity to export will be the sum of two terms. The first accounts for the direct effect of a change in that variable on the probability that *dEXP* equals 1, while the second measures the indirect effect of the change in *Prod* on the probability that *dEnvInno* equals 1 which, in turn, affects the probability that *dEXP* equals 1. Estimates reported in Table 2 confirm that heterogeneity of productivity across firms matters, and Prediction 2 is confirmed. It is in line with the existing literature [Melitz and Redding (2014), Bernard and Jensen (1999)]. For German manufacturing firms, it has a positive and statistically significant marginal effect on exporting propensity, both directly and indirectly through the effect on eco-innovation induced by regulation. Productivity especially affects firms' exporting status directly. As Table 2 shows, direct marginal effects are higher than indirect ones; a marginal change in productivity produces a 0.20% increase of the propensity of being an exporter. Moreover, if we compare the two German samples, we can see from Column 2 that the indirect marginal effect of productivity is higher for innovators (0.064%) than for the sample of all firms (0.028%). Thus more productive and already innovative firms have a higher propensity to adopt an eco-innovation since an environmental regulation is imposed and, consequently, to be an exporter. Concerning EE firms, in contrast to coefficients, marginal effects analysis have recorded a lower level of significance for productivity. The total marginal effect of productivity on exporting propensity is statistically significant and an increase of 1% in productivity generates an increase of 0.13% of the probability of exporting.

Finally, to give a more precise measure of productivity effects, the marginal effect of being a medium or large firm on exporting probability has been investigated[21]. This is justified by the fact that size is correlated with productivity (Prediction 3) and *Prod* variable is constructed by taking total revenues given that there is insufficient information to get labor productivity or profitability measures. Specifically, the marginal effect is the export probability change that is calculated comparing medium/large to small sized firms and is the sum of two terms. The first one refers to the effect of the implementation when firms are eco-innovators driven by a regulation (*dEnvInno*=1); while, the second one captures the effect of size for non-eco-innovators driven by a regulation (*dEnvInno*=0). According to Andries and Stephan (2019), who have analysed the impact on the relationship of size and eco-innovation of Flemish firms' financial performance, we

[21] By analysing our samples, 55.9% of the German sample is represented by medium/large firms while, if we consider the EE sample, the share of medium/large firms equals 42.26% of the sample.

can highlight that being a medium-sized or large firm (compared to a small one), if an eco-innovation is not implemented, has a negative marginal effect on the probability of being an exporter. Therefore, a size change is not sufficient to be more competitive in terms of exports, but it is necessary to adopt an eco-innovation as well. This result is confirmed for both samples of German firms, which show a marginal decrease of 9.1% and 10.3% respectively. These results suggest that Prediction 3 is verified, and a possible complementarity between size and eco-innovation decisions can be identified for German firms. By considering EE firms, the exporting probability marginally increases by 9.3% if a firm becomes medium or large both for eco-innovators and non-eco-innovators, so size and eco innovation seem to independently affect a firm's performance.

4.2 Destination markets, firm's heterogeneity and eco-innovation induced by regulation

A further investigation of the effect of environmental regulation induced by eco-regulation on firms' competitiveness is conducted to deal with different kinds of exporters, classified by destination markets. Since a substantial productivity and size heterogeneity across firms is detected, trade strategies are more complex than a dichotomous variable can describe.

Considering these aspects and taking into account the literature on the relationship between destination markets and exporting decisions [Melitz (2003)], we have studied the impact of environmental innovation induced by regulation by accounting for different groups of exporters classified by supplied markets. Firms must pay for fixed costs in every foreign market to which they export. That is why, when the number of destination markets increases, export costs increase as well. It is also true that by adding new destination markets, firms are asked to bear higher trade costs relating to more geographically and culturally distant markets. These facts imply that firms will be ordered in export decisions by productivity. The least productive firms will be non-exporters, the medium productive ones will export to one (and/or close) destination market, and the most productive ones can get positive profits by selling to multiple (and more distant) destination markets. Our research question is to assess whether eco-innovation decisions differently affect a firms' performance depending upon their ability to sell to domestic and/or foreign consumers located in close or distant markets. Empirically, the dependent variable, represented by the exporting choice (*EXP*), is a categorically ordered variable; the higher the value of *EXP*, the larger the supplied market. Specifically, *EXP* is 0 if a firm does not export (non-exporter), 1 if it exports only to EU countries (Exporter 1) and 2 if it supplies products to both EU and extra-EU countries (Exporter 2). The specific idea is to capture the impact of the eco-innovation variable, *dEnvInno*, on the level of the market involvement of firms.

Table 3. Destination markets and eco-innovation induced by regulation - Descriptive frequencies and percentages

	Germany				East European Countries			
	EXP							
dEnvInno	*0*	*1*	*2*	**Total**	*0*	*1*	*2*	**Total**
0	406	211	496	1113	60	158	271	489
1	243	197	623	1063	273	607	1154	2034
missing	160	112	441	713	6761	5714	3389	15864
Total	809	520	1560	**2889**	7094	6479	4814	**18387**
0	14,05%	7,30%	17,17%	38,53%	0,33%	0,86%	1,47%	2,66%
1	8,41%	6,82%	21,56%	36,79%	1,48%	3,30%	6,28%	11,06%
missing	5,54%	3,88%	15,26%	24,68%	36,77%	31,08%	18,43%	86,28%
Total	28,00%	18,00%	54,00%	**100%**	38,58%	35,24%	26,18%	**100%**

For both Germany and EE countries, Table 3 underlines that a possible positive correlation between the adoption of eco-innovation induced by regulation and destination markets is recognized; the share of firms that adopt an environmental innovation since a regulation has been imposed is higher for exporters selling to both intra and extra EU customers. Specifically, the relative weight of eco-innovators that export to both markets equals 21.56% for Germany and 6.28% for EE Countries.

The testing procedure requires the estimation of a model that accounts for the ordered categorical nature of the dependent variable *EXP*. Given this aspect, the ESM model is estimated by replacing the equation (11) with an ordered probit equation that includes the same explanatory variables (Model 2). Corresponding marginal effects are reported in Table 4[22].

[22] For this estimation, coefficients are not reported but are available upon request.

Table 4. Destination markets, firm's heterogeneity and eco-innovation induced by regulation (Marginal Effects - Model 2)

	Germany				**East European Countries**			
	All sample		*Innovators*		*All sample*		*Innovators*	
	Exporter 1	Exporter 2	Exporter 1	Exporter 2	Exporter 1	Exporter 2	Exporter 1	Exporter 2
EXP								
dEnvInno	-0.004	0.033***	0.001	-0.009***	0.029	-0.062***	0.030	-0.063***
	(0.012)	(0.010)	(0.003)	(0.003)	(0.021)	(0.015)	(0.021)	(0.015)
Prod								
Direct effect	0.027	0.202***	0.034	0.206***	0.073	0.154***	0.073	0.154***
	(0.072)	(0.064)	(0.070)	(0.064)	(0.051)	(0.037)	(0.050)	(0.037)
Indirect effect	0.016**	0.045*	0.017	0.051**	0.017	0.029	0.016	0.028
	(0.008)	(0.027)	(0.008)	(0.026)	(0.014)	(0.021)	(0.014)	(0.021)
Total	0.048	0.247***	0.058	0.255***	0.091**	0.182***	0.091**	0.181***
	(0.070)	(0.072)	(0.065)	(0.071)	(0.045)	(0.045)	(0.045)	(0.045)
Medium/Large Firms								
dEnvInno=1	0.021**	0.025	0.020*	0.008	-0.086**	0.149***	-0.086**	0.151***
	(0.010)	(0.028)	(0.011)	(0.025)	(0.042)	(0.048)	(0.042)	(0.047)
dEnvInno=0	-0.017**	-0.043*	-0.013**	-0.038**	0.008	0.019*	0.007	0.018*
	(0.008)	(0.025)	(0.006)	(0.019)	(0.006)	(0.011)	(0.006)	(0.010
Total	0.004	-0.019	0.007	-0.030*	-0.078*	0.168***	-0.078*	0.169***
	(0.008)	(0.015)	(0.012)	(0.016)	(0.046)	(0.042)	(0.046)	(0.041)
N. obs	2889		2233		18387		5442	
Log Likelihood	-2812.37		-2555.89		-3143.94		-3125.16	
Wald chi2	918.66***		706.72***		702.20***		691.41***	
Cut-point 1	-0.654***		-0.634***		-1.276***		-1.282***	
	(0.205)		(0.217)		(0.244)		(0.246)	
Cut-point 2	0.010		0.025		-0.136		-0.140	
	(0.205)		(0.216)		(0.241)		(0.242)	

Note. Significance levels: *** 0.01, ** 0.05, * 0.1

638 Before commenting on the obtained results, we need to introduce cut points for the computation 639 of marginal effects. Since our dependent variable takes three possible values, two cut-points are 640 estimated. Cut-point 1 represents the estimated cut point on the latent variable used to differentiate 641 non exporters from exporters (both Exporter 1 and Exporter 2). It is the corresponding intercept of 642 the regression equation with a reversed sign [Greene (2003)]. As we can see from Table 4, firms 643 that show a latent variable EXP_i^* value less than (or equal to) -0.654, -0.634, -1.276 and -1.282, 644 depending on the considered sample, can be classified as non-exporters. Similarly, Cut-point 2 645 differentiates the group of non-exporters and Exporters 1 together from Exporters 2. All firms that 646 have a latent variable EXP_i^* value more than 0.010, 0.025, -0.136 and -0.140, respectively, are 647 classified as Exporters 2. Firms that are Exporters 1 are identified by difference; the value of their 648 latent EXP_i^* lies between Cut-point 1 and Cut-point 2.

649 Marginal effects reported in Table 4 allow us to provide further insights on previous results. First, 650 concerning German manufacturing firms, prediction 1 is confirmed in its positive declination, so 651 the effect of environmental innovation guided by a regulation on exporting propensity is robust. 652 Moreover, we are able to assert that the positive marginal effect connected with the strong PH and 653 found through Model 1 estimation, is specifically connected to eco-innovation decisions of non-654 innovative firms and it especially affects the propensity of being an Exporter 2. If we compare the 655 statistically significant marginal effects of the sample of all firms and the generic innovators 656 sample, we can see that, among the latter group of firms, being an eco-innovator induced by 657 regulation decreases the propensity of being an Exporter 2 by 0.9%; while, referring to the former, 658 this status increases the probability of exporting to both EU and extra EU markets by 3.3%. This 659 result explains a possible barrier for firms that innovate: the introduction of an environmental 660 regulation, if a firm has already implemented one type of innovation, implies that the decision to

introduce an eco-innovation, or to implement an additional one, worsens a firms performance when it is involved in several foreign markets. For these firms, the costs connected with both conventional and environmental innovation are not counterbalanced by revenues, even if they sell products in both EU and extra EU countries. Conversely, if non-innovative firms are also accounted for, an environmental tax/fee or charges represents an opportunity; they can gain a higher competitiveness in terms of exporting probability if they introduce an eco-innovation, though they need a sufficiently large market including both EU and extra-EU countries [Melitz (2003), Bustos (2011)]. Focusing on EE firms, Prediction 1, in its negative declination, has already been confirmed, and the corresponding negative results have been found for Model 1, so the existence of the PHE, is confirmed for both samples and it is related to the propensity of being an Exporter 2 (both intra and extra-EU). In this context, not all types of firms can face the higher compliance costs connected with environmental regulation by introducing eco-innovation and a decrease of 6.2% and 6.3% of the probability of exporting outside the EU.

Further considerations can also be made about productivity and heterogeneity. As we have already asserted in the previous section, the level of productivity plays a relevant role in both the adoption of eco-innovation due to the existence of regulation and the propensity for being an exporter. If we analyse the total effect of productivity, we can argue that a 1% increase in productivity implies that German firms are 0.25% more likely to export to both intra and extra EU countries. The total effect is especially related to the direct effect of productivity on export status (around 0.20%); the residual value concerns the indirect marginal effect, which operates through the eco-innovation adoption. This is true for both samples. As we can see from Column 2, the total positive effect is not statistically significant in the case of Exporter 1. Furthermore, the indirect marginal effect is positive for both Exporter 1 and Exporter 2 (all firm sample), and for Exporter 2 only in the generic

684 innovator sample. This result suggests that Prediction 2 is confirmed, so the results are robust. More specifically, if we also take into account the non-innovative firms, being more productive fosters eco-innovation adoption driven by regulation, and in turn export propensity is positively affected. Different outcomes are recorded for EE firms; a positive and statistically significant total marginal effect is obtained, mainly driven by the direct effect for both Exporter 1 and Exporter 2-type firms. Prediction 2 is not verified and productivity gains do not affect export propensity through eco-innovation adoption. As shown by Columns 5-8, results are very similar for the two samples. We can conclude that there are no significant differences between them. At any rate, these results are in line with the literature which highlights that more productive firms tend to export products to more destination markets.

Finally, concerning size heterogeneity, marginal effects calculated from Model 2 confirm the results of the Model 1 analysis. For German firms, being a medium or large firm is not sufficient to be an exporter and eco-innovation decisions are complements for producing positive effects on firm performance, so Prediction 3 is verified. Columns 1-4 highlights this result: if an environmental innovation is adopted, because a regulation exists, a medium/large firm is more likely to supply its products to EU countries than a small one; the marginal increase equals 2%. The effect on Exporter 2 propensity is statistically negligible. However, if an eco-innovation induced by environmental regulation is not introduced, the propensity for being an Exporter 1 or 2 decreases from small to medium or large sized firms. The overall marginal effect of size is mostly affected by non-eco-innovators. For EE firms, a slightly different scenario on size can be defined. Differently from Model 1 estimates, if firms are classified into the three groups by the *EXP* variable, a correlation between eco-innovation decisions and size is a necessary but not sufficient condition to guarantee the positive effects on firm performance. When adopting an environmental innovation, the medium or large firm probability of exporting to both EU and extra EU countries is higher by around 15% than small firms. On the contrary, given that they implement an eco-innovation induced by environmental regulation, the marginal effect on being an Exporter 1 is negative and statistically significant; it equals -8.6% for all firms and innovator samples. Economically, this result implies that medium or large firms seem to be more efficient provided that they sell products to both intra and extra EU customers; they can bear the higher costs of the advanced innovation adoption and exporting if and only if they are Exporters 2.

5. Conclusions

In a scenario where trade and innovation play a relevant role for sustainable development, and where environmental policies are constantly strengthened in order to preserve natural resources and to account for climate change, many researchers have studied links between environmental policy, eco-innovation and trade performance. The existing evidence has underlined a strong correlation among all these aspects, especially at macro and meso level. This paper has contributed to the literature on *strong* PH and PHE by considering the role of firms' productivity and size heterogeneity on environmental regulation, eco-innovation and trade decisions nexus in German and EE firms. Specifically, results support the hypothesis that heterogeneity across firms is important in defining this relationship, not only in terms of productivity, technology and size, but also by considering the complexity of a firm's export portfolio.

Our analysis has provided several findings. First, both *strong* PH and PHE are confirmed depending on the firms' geographical localisation, Germany and EE, so we can say that these theories are not competing. Results regarding German firms show that the higher compliance costs of regulation are coupled with positive effects related to a reallocation of market shares generated by the exit of firms after the introduction of the new or more stringent eco-regulation. This result confirms a theoretical analysis that includes environmental regulation and the adoption of abatement technology in a framework based on Melitz (2003), and it supports a *strong* PH. An opposite result is obtained for EE countries, where PHE prevails and firms are not able to bear the higher compliance costs by implementing eco-innovation, so they are less efficient and consequently less likely to be exporters. **In line with the existing literature, we can assert that results differ by country. In addition to the existing literature, we are able to explicitly identify the driving factors of PHE and *strong* PH, when exporting decisions are considered. On one hand, the PHE is strictly connected with firms located in less advanced and less innovative European countries (i.e. EE countries). Being a competitive and efficient firm in this area is difficult; the introduction of an environmental regulation reduces the propensity of being competitive, even if a productivity-enhancing effect of environmental innovation exists. Firms should be enough large to achieve a minimum level of competitiveness. On the other hand, more advanced and highly innovative countries, such as Germany, have a socio-economic fabric that constantly supports firms' development. Firms located in these countries are already innovative and prepared to compete on global markets, so they can bear the costs of the implementation of the environmental regulation and advantages, in terms of trade.**

Furthermore, by analysing direct, indirect and total effects of productivity on the exporting propensity of firms, we have found that productivity is an important driver in explaining the relationship among environmental regulation, eco-innovation and firms' performance. Generally, productivity especially affects firms exporting performance directly but its indirect effect through the adoption of an abatement technology is also at work for generic innovators. Thus, more productive innovators have a higher probability of being eco-innovators and, consequently, to export. Furthermore, heterogeneity across firms in terms of size represents another fundamental factor in explaining the eco-regulation, eco-regulation and trade decisions nexus. **Through this specific analysis, we have contributed to the existing debate by confirming that the propensity of being an eco-innovator is driven by productivity, and by also giving evidence that this positive relationship is stronger for firms that already innovate, regardless of the type of innovation.**

Finally, a robustness analysis by considering different kinds of exporters relating to the number of destination markets has been conducted. Results on PHE and *strong* PH are robust and can be attributed especially to the most productive and largest firms that can export to both intra- and extra-EU countries. **With respect to the existing contributions on the relationship between eco-regulation, environmental innovation and trade decisions at micro level, we evaluate the role of export complexity by taking into account the dimension of supplied markets. Moreover, we confirm Bustos (2011) theoretical predictions on innovation, by finding a positive effect of environmental innovation on the propensity of exporting.**

From a policy point of view, different insights can be made. Since our results suggest that size, productivity, geographical location, innovation decisions are strictly correlated and define the entity and the competitiveness of firms, international authorities should carefully consider all these interactions and implement environmental regulation by carefully considering firms' heterogeneity. We have seen that, for certain types of firms, the mere introduction of an environmental regulation alone is not sufficient to foster eco-innovation adoption and, consequently, to improve firms' propensity for exporting; specifically, this kind of regulation may foster firms' performance if and only if firms are sufficiently efficient to cope with the higher compliance costs related to the regulation. This means that the definition of environmental regulation should be conceived with other policies, such as industrial ones. Only following this direction, an integrated policy framework that addresses trade, industrial, technological and ecological transition dependencies can be drawn. A clear example is represented by the updated EU New Industrial Strategy of 2020. According to our results, we would suggest either an incentive regime or lower compliance costs connected with a regulation to impede the exit of the least productive and smallest firms from the market, to support the implementation of both innovation and eco-innovation to improve efficiency and trade competitiveness, which are necessary in the transition toward a more sustainable scenario. By considering these aspects, strong effort could be made to ensure access to a competitively priced clean technology throughout the market. Nevertheless, a technology and knowledge transfer from the advanced EU countries to less developed ones already exists. This opportunity should be outlined especially for less advanced and emerging countries which may invest more resources to innovate and to foster productivity for all their firms; this may help in the process of catching up as well.

From an economic perspective, our work can give important insights into the current EU debate on the relationship among relevant environmental aspects, the role played by firms and their trade decisions. Nevertheless, useful information is missing at firm level and the dataset is cross section in nature. Regarding the available information, we cannot disentangle environmental regulation from eco-innovation adoption and type, so that we partially test our theoretical predictions on PHE and *strong* PH. With more detailed data on the nature of this variable, a more accurate analysis could be done on how environmental regulation impacts on firms' decisions in the selected sample. Furthermore, information to draw a more precise productivity or TFP variable would be needed. Finally, we cannot give precise

insights about intertemporal eco-innovation decisions since the dataset lacks repeated observations over time.

By considering the contribution of our paper and its limitations, further interesting research can be developed. A first extension might distinguish between types of eco-innovation, such as end-of-pipe and cleaner technologies for production, to account for different levels of fixed and variable innovation costs, which may have differentiated effects on firm exporting decisions, as predicted by Bustos (2011). For example, it can be assumed that an end-of-pipe technology requires higher fixed costs only, while the introduction of a cleaner production technology is associated with higher fixed but lower variable costs, than end-of-pipe and dirty-type ones. Moreover, these kinds of eco-innovation can be independently or complementarily adopted by firms, so a study on the joint adoption of these technologies and their drivers can contribute to broaden the research field on the possible mitigation of the environmental burden of production. A second extension could consider the structure of firms. Knowing if a firm is part of an enterprise group, if it is the headquarter and where it is located can provide insights on the geographical distribution and composition of firms in the two European areas. By taking into account these firm characteristics, countries can improve and implement infrastructure management policies to attract foreign firms and to discourage domestic firms to leave the country. Moreover, further investigation on knowledge transfer could be supplied. Finally, given that an EU environmental regulation is usually adopted at different times and through multiple measures at the country level, a quasi-experiment estimation, by means of a difference in difference treatment effect model, could be implemented to tease out the causal relationship among regulation, innovation and trade decisions.

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Appendix A – Mathematical derivation of industry equilibrium

We look for the value of domestic cut-off for dirty-type firms such that the industry is in equilibrium, so the zero-profit condition (8) and the free entry condition (9) have to be satisfied. We can write δf_e as follows

(A1) $$\delta f_e = f_d k(DD)[1 - G(DD)] + f_d^* k(DF)[1 - G(DF)] + \Delta f k(\tilde{\varphi})[1 - G(\tilde{\varphi})]$$

where

(A2) $$k(i) = \left[\frac{\bar{\varphi}(i)}{i}\right]^{\varepsilon-1} - 1 \qquad i = DD, DF, \tilde{\varphi}$$

(A3) $$\bar{\varphi}(i) = \left[\frac{1}{1-G(i)}\int_i^{\infty} \varphi^{\varepsilon-1} g(\varphi) d\varphi\right]^{\frac{1}{\varepsilon-1}}$$

(A4) $$\Delta f = f_c + f_c^* - f_d - f_d^*$$

Let define $J(i) \equiv k(i)[1 - G(i)]$. Following Melitz (2003), we can demonstrate that $J(i) > 0$ and $J'(i) < 0$.
By substituting $J(i)$ into Equation (A1), we obtain

(A5) $$\delta f_e = f_d\, J(DD) + f_d^*\, J(DF) + \Delta f\, J(\tilde{\varphi})$$

By differentiating Equation (A5) with respect to t, we can study the effect of a change of the environmental tax on DD

(A6) $$\frac{d\delta f_e}{dt} = f_d\, J'(DD)\frac{dDD}{dt} + f_d^*\, J'(DF)\frac{dDF}{dt} + \Delta f\, J'(\tilde{\varphi})\frac{d\tilde{\varphi}}{dt} = 0$$

Firstly, we calculate $\frac{dDF}{dt}$ and $\frac{d\tilde{\varphi}}{dt}$, that represent the derivative of (4) and (7) with respect to t.

(A7) $$\frac{dDF}{dt} = \tau \left(\frac{f_d^*}{f_d}\right)^{\frac{1}{\varepsilon-1}} \frac{dDD}{dt}$$

(A8) $$\frac{d\tilde{\varphi}}{dt} = \frac{dDD}{dt}\frac{\tilde{\varphi}}{DD} - \frac{\tilde{\varphi}}{1+t}\, a$$

where $a = \frac{1}{1-\left[\frac{c(1+t)}{c_c}\right]^{\varepsilon}}$. The obtained values are substituted in equation (A6) and we get

(A9) $$\frac{dDD}{dt} = \frac{DD}{1+t}\, a\, b$$

where $b = \frac{\Delta f\, J'(\tilde{\varphi})\, \tilde{\varphi}}{f_d\, J'(DD)\, DD + f_d^*\, J'(DF)\, DF + \Delta f\, J'(\tilde{\varphi})\, \tilde{\varphi}}$.
It is easy to show that Equation (B9) is positive. Since $a > 0$ and $0 < b < 1$, then the derivative $\frac{dDF}{dt} > 0$ too.
As regards to the effect of t on the adoption cut-off $\tilde{\varphi}$, we have to calculate the derivative of $\tilde{\varphi}$ with respect to t.

(A10) $\frac{d\tilde{\varphi}}{dt} = \frac{\tilde{\varphi}}{1+t}\, a\, [b - 1]$

Since $0 < b < 1$, this derivative is negative.

Appendix B

Table B.1. Manufacturing sectors description Germany

Nace Rev. 2	Description
C10_C12	Manufacture of goods, products, beverage, tobacco products
C13	Manufacture of textile
C14_C15	Manufacture of wearing apparel, leather and related products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31	Manufacture of furniture
C32	Other manufacturing
C33	Repair and installation of machinery and equipment

Table B.2. Manufacturing sectors description East European Countries

Nace Rev. 2	Description
C10_C12	Manufacture of goods and products, beverage and tobacco products
C13_C15	Manufacture of textile, wearing apparel, leather and related products
C16_C17	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19_C21	Manufacture of coke and refined petroleum products, chemicals and chemical products, basic pharmaceutical products and pharmaceutical preparations
C22_C23	Manufacture of rubber and plastic products, other non-metallic mineral products
C24_C25	Manufacture of basic metals and fabricated metal products, except machinery and equipment
C26_C28	Manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment n.e.c.
C29_C30	Manufacture of motor vehicles, trailers and semi-trailers, other transport equipment
C31_C32	Manufacture of furniture and other manufacturing
C33	Repair and installation of machinery and equipment, other manufacturing

Table B.3 Variables Description Germany

Variable	Description
dEXP	Dummy variable that refers to exporting propensity of firms: equal to 1 if firm exports, 0 otherwise
EXP	Ordered variable that refers to trade openness of a firm: equals to 2 if a firm exports to both intra and extra European Union countries; equals to 1 if a firm exports to intra European Union countries only; equals to 0 if a firm does not export
dEnvInno	Dummy related to the introduction of eco-innovation: equal to 1 if firm introduces an eco-innovation because an eco-regulation(tax, fee, charge) has been introduced, 0 otherwise
rd	Dummy related to the introduction of R&D: equals to 1 if activities to create new knowledge or to solve scientific or technical problems have been implemented, 0 otherwise
CoAll	Dummy related to cooperation for innovation activities: equals 1 if a firm has co-operated on any of its innovation activities with other enterprises or organisations, 0 otherwise
Prod	Firms' s relative profitability, Aw et al. (2010)
dsmall	Dummy equals to 1 if firm has <50 employees, 0 otherwise
dmedium	Dummy equals to 1 if firm has a number of employees between 50 and 250, 0 otherwise
dlarge	Dummy equals to 1 if firm has >250 employees, 0 otherwise
ds1-ds20	20 dummies referring to sectors at *2-digit* level Nace Rev. 2 classification

Table B.4 Variables Description East European Countries

Variable	Description
dEXP	Dummy variable that refers to exporting propensity of firms: equal to 1 if firm exports, 0 otherwise
EXP	Ordered variable that refers to trade openness of a firm: equals to 2 if a firm exports to both intra and extra European Union countries; equals to 1 if a firm exports to intra European Union countries only; equals to 0 if a firm does not export
dEnvInno	Dummy related to the introduction of eco-innovation: equal to 1 if firm introduces an eco-innovation because an eco-regulation (tax, fee, charge) has been introduced, 0 otherwise
rdExp	Total expenditure on innovation activities
Reput	Dummy related to firm's reputation in terms of environmental issues: it equals 1 if a firm has procedures in place to regularly identify and reduce environmental impacts, 0 otherwise
Prod	Firms' s relative profitability, Aw et al. (2010)
dsmall	Dummy equals to 1 if firm has <50 employees, 0 otherwise
dmedium	Dummy equals to 1 if the number of employees lies between 50 and 250, 0 otherwise
dlarge	Dummy equals to 1 if firm has >250 employees, 0 otherwise
ds1-ds11	11 dummies referring to sectors at *2-digit* level Nace Rev. 2 classification

Table B.5 Summary statistics Germany

Variable	Obs	Mean	Std. Dev.	Min	Max
dEXP	2,987	.7291597	.4444682	0	1
EXP	2,889	1.259.952	.8675786	0	2
dEnvInno	2,276	.4912127	.5000326	0	1
Prod	3,249	-2.30e-07	2.111821	-6.394152	6.494511
dsmall	3,250	.4230769	.4941234	0	1
dmedium	3,250	.3043077	.4601844	0	1
dlarge	3,250	.2726154	.4453732	0	1
ds1	3,250	.0907692	.2873249	0	1
ds2	3,250	.0304615	.17188	0	1
ds3	3,250	.028	.1649981	0	1
ds4	3,250	.0258462	.1587006	0	1
ds5	3,250	.0295385	.1693362	0	1
ds6	3,250	.056	.2299571	0	1
ds7	3,250	.0215385	.1451931	0	1
ds8	3,250	.0544615	.2269611	0	1
ds9	3,250	.0406154	.1974279	0	1
ds10	3,250	.0366154	.1878445	0	1
ds11	3,250	.1086154	.3112039	0	1
ds12	3,250	.1009231	.3012732	0	1
ds13	3,250	.0541538	.2263559	0	1
ds14	3,250	.1224615	.3278686	0	1
ds15	3,250	.0424615	.2016707	0	1
ds16	3,250	.0190769	.1368165	0	1
ds17	3,250	.0236923	.1521121	0	1
ds18	3,250	.0384615	.1923373	0	1
ds19	3,250	.0501538	.2182959	0	1
ds20	3,250	.0261538	.1596172	0	1
rd	2,585	.6796905	.4666857	0	1
CoAll	2,975	.3173109	.4655078	0	1

Table B.6 Summary Statistics East European Countries

Variable	Obs	Mean	Std. Dev.	Min	Max
dEXP	18,951	.6256662	.4839632	0	1
EXP	18,387	.8759993	.7951665	0	2
dEnvInno	2,567	.8040514	.3970065	0	1
Prod	19,102	2.55e-08	1.570429	-9.12181827	7.707259
dsmall	19,134	.577506	.4939692	0	1
dmedium	19,134	.3334379	.4714538	0	1
dlarge	19,134	.0890561	.2848322	0	1
ds1	19,134	.1712658	.3767509	0	1
ds2	19,134	.1778509	.3823972	0	1
ds3	19,134	.0829936	.2758798	0	1
ds4	19,134	.0276471	.1639639	0	1
ds5	19,134	.0385701	.192573	0	1
ds6	19,134	.1052577	.3068931	0	1
ds7	19,134	.1345772	.3412803	0	1
ds8	19,134	.1176962	.3222565	0	1
ds9	19,134	.036375	.1872264	0	1
ds10	19,134	.0748406	.2631408	0	1
ds11	19,134	.0329257	.1784468	0	1
rdExp	5,298	.0672238	.8411876	0	36.73967
Reput	19,060	.194596	.3958998	0	1

Table B.7 Correlation Matrix - Germany

Germany	*dEXP*	*dEnvInno*	*Prod*	*dsmall*	*dmedium*	*dlarge*	*CoAll*	*rd*
dEXP	1							
dEnvInno	0.1487*	1						
Prod	0.3204*	0.2333*	1					
dsmall	-0.3317*	-0.2340*	-0.6750*	1				
dmedium	0.1190*	0.0654*	-0.0086	-0.5664*	1			
dlarge	0.2547*	0.2236*	0.7576*	-0.5243*	-0.4049*	1		
CoAll	0.2881*	0.1333*	0.3641*	-0.2357*	-0.0952*	0.3758*	1	
rd	0.4124*	0.2604*	0.3399*	-0.3213*	0.0106	0.3295*	0.5627*	1
	EXP	*dEnvInno*	*Prod*	*dsmall*	*dmedium*	*dlarge*	*CoAll*	*rd*
EXP	1							
dEnvInno	0.1580*	1						
Prod	0.3648*	0.2333*	1					
dsmall	-0.3812*	-0.2340*	-0.6750*	1				
dmedium	0.1192*	0.0654*	-0.0086	-0.5664*	1			
dlarge	0.3109*	0.2236*	0.7576*	-0.5243*	-0.4049*	1		
CoAll	0.3459*	0.1333*	0.3641*	-0.2357*	-0.0952*	0.3758*	1	
rd	0.4602*	0.2604*	0.3399*	-0.3213*	0.0106	0.3295*	0.5627*	1

Note. Significance level: 5%

Table B.8 Correlation Matrix - East European Countries

East Europe Countries	*dEXP*	*dEnvInno*	*Prod*	*dsmall*	*dmedium*	*dlarge*	*rdExp*	*Reput*
dEXP	1							
dEnvInno	-0.0156	1						
Prod	0.3804*	0.1302*	1					
dsmall	-0.3196*	-0.0949*	-0.6245*	1				
dmedium	0.2227*	0.0174	0.3539*	-0.8269*	1			
dlarge	0.1852*	0.0893*	0.4970*	-0.3656*	-0.2211*	1		
rdExp	-0.0084	0.0176	-0.0856*	0.0208	-0.0249	0.0050	1	
Reput	0.2123*	0.2142*	0.3026*	-0.2616*	0.1319*	0.2352*	-0.0139	1
	EXP	*dEnvInno*	*Prod*	*dsmall*	*dmedium*	*dlarge*	*rdExp*	*Reput*
EXP	1							
dEnvInno	0.0009	1						
Prod	0.4516*	0.1302*	1					
dsmall	-0.3697*	-0.0949*	-0.6245*	1				
dmedium	0.2351*	0.0174	0.3539*	-0.8269*	1			
dlarge	0.2516*	0.0893*	0.4970*	-0.3656*	-0.2211*	1		
rdExp	0.0045	0.0176	-0.0856*	0.0208	-0.0249	0.0050	1	
Reput	0.2902*	0.2142*	0.3026*	-0.2616*	0.1319*	0.2352*	-0.0139	1

Note. Significance level: 5%

Table B.9 Instrumental Variables Tests Germany (All sample)

	1	2
First stage		
Test for excluded instruments	F (2, 1677) = 29.76***	F (2, 1622) = 24.72***
H_0: the endogenous regressor is unidentified		
Underidentification test		
H_0: matrix of reduced form coefficients has rank=K1-1		
Kleinbergen-Paap rank LM statistic	Chi sq. (2) = 55.78***	Chi sq. (2) = 47.04***
Weak-instrument robust inference		
H_0: the endogenous regressor coefficient is equal to 0 and the overidentifying restrictions are valid		
Anderson-Rubin Wald test	F (2, 1677) = 24.44***	F (2, 1622) = 32.14
Anderson-Rubin Wald test	Chi sq. (2) = 49.60***	Chi sq. (2) = 65.27***
Stock-Wright LM S statistic	Chi sq. (2) = 49.87***	Chi sq. (2) = 63.54***
Second stage		
Overidentification test		
H_0: the instruments are valid instruments and are uncorrelated with error term		
Hansen J statistic	Chi sq. (1) = 0.001	Chi sq. (1) = 0.145
N. observations	1702	1647
N. regressors	24	24
N. endogenous regressors	1	1
N. instruments	25	25
N. of excluded instruments	2	2

*Specification: The model specifications use different variables for the exporting propensity of firms: 1. dEXP; 2. EXP. Note: Significance levels: *** 0.01, ** 0.05, * 0.1. Tests on instruments related to innovators sample are not reported but they are available upon request.*

Table B.10 Instrumental Variables Test East European Countries (All Sample)

	1	2
First stage		
Test for excluded instruments	F (2, 2223) = 46.86***	F (2, 2191) = 45.74***
H_0: the endogenous regressor is unidentified		
Underidentification test		
H_0: matrix of reduced form coefficients has rank=K1-1		
Kleinbergen-Paap rank LM statistic	Chi sq. (2) = 74.54***	Chi sq. (2) = 72.84***
Weak-instrument robust inference		
H_0: the endogenous regressor coefficient is equal to 0 and the overidentifying restrictions are valid		
Anderson-Rubin Wald test	F (2, 2223) = 0.420	F (2, 2191) = 1.800
Anderson-Rubin Wald test	Chi sq. (2) = 0.840	Chi sq. (2) = 3.62
Stock-Wright LM S statistic	Chi sq. (2) = 0.870	Chi sq. (2) = 3.35
Second stage		
Overidentification test		
H_0: the instruments are valid instruments and are uncorrelated with error term		
Hansen J statistic	Chi sq. (1) = 0.101	Chi sq. (1) = 0.286
N. observations	2239	2207
N. regressors	15	15
N. endogenous regressors	1	1
N. instruments	16	16
N. of excluded instruments	2	2

*Specification: The model specifications use different variables for the exporting propensity: 1. dEXP; 2. EXP. Note: Significance levels: *** 0.01, ** 0.05, * 0.1. Tests on instruments related to innovators sample are not reported but they are available upon request.*

Appendix C - Marginal effects in bivariate non-linear models

Given the following bivariate probit model (Model 1),

(C1) $$\begin{cases} y_1^* = \beta_1' x_1 + \gamma y_2 + \varepsilon_1 \\ y_2^* = \beta_2' x_2 + \varepsilon_2 \end{cases} \text{ with } \quad (\varepsilon_1, \varepsilon_2) \sim BVN[0,0,1,1,\rho]$$

where y_i^*, $i = 1,2$ are latent and continuous variables, associated with observed discrete variables

(C2) $$y_i = \begin{cases} 1 & when\ y_i^* > 0 \\ 0 & otherwise \end{cases}, i = 1,2$$

and BVN is the BiVariate Normal density function.

Greene (1998) shows how to calculate the marginal effects of the covariates in the conditional and marginal distributions. Calculations are made by assuming the correlation of the two equations $\rho = 0$. The conditional probability of $y_1 = 1$ given y_2 (either 1 or 0) is

(C3) $$p[y_1 = 1 | y_2, x_1, x_2] = \frac{BCF(c_1, q_2 c_2, \rho^*)}{\Phi(q_2 c_2)}$$

where BCF is the Bivariate normal Cumulative Function, and

(C4) $$c_1 = \beta_1' x_1 + \gamma y_2$$

(C5) $$c_2 = \beta_2' x_2$$

(C6) $$\rho^* = q_2 \rho$$

with $q_2 = \begin{cases} +1 & when\ y_2 = 1 \\ -1 & when\ y_2 = 0 \end{cases}$. When $\rho = 0$, it is shown that $BCF(c_1, c_2, 0) = \Phi(c_1)\Phi(c_2)$,.

Then, the marginal effect of the endogenous binary variable y_2 is

(C7) $$p[y_1 = 1 | y_2 = 1, x_1, x_2] - p[y_1 = 1 | y_2 = 0, x_1, x_2] = \frac{BCF(c_1^1, c_2, \rho)}{\Phi(c_2)} - \frac{BCF(c_1^0, -c_2, -\rho)}{\Phi(-c_2)} = \Phi(c_1^1) - \Phi(c_1^0)$$

where $c_1^1 = \beta_1' x_1 + \gamma$ and $c_1^0 = \beta_1' x_1$.

Second, the marginal effect of an exogenous binary variable $d = [x_1, x_2]$ is

(C8) $$p[y_1 = 1 | d = 1] - p[y_1 = 1 | d = 0] = BCF(c_1^1, c_2, \rho |\ d = 1) + BCF(c_1^0, -c_2, -\rho |\ d = 1) - BCF(c_1^1, c_2, \rho |\ d = 0) - BCF(c_1^0, -c_2, -\rho |\ d = 0) =$$

$$= [\Phi(c_2)\ \Phi(c_1^1) + \Phi(-c_2)\ \Phi(c_1^0)] | d = 1 - [\Phi(c_2)\ \Phi(c_1^1) + \Phi(-c_2)\ \Phi(c_1^0)] | d = 0$$

Finally, the marginal effect of a (continuous) covariate $w = [x_1, x_2]$ is obtained as follows:

(C9) $$\frac{\partial p[y_1=1|y_2,x_1,x_2]}{\partial w} = \frac{g_1(c_1,q_2c_2,\rho^*)}{\Phi(q_2c_2)}\beta_1^w + \frac{\Phi(q_2c_2)g_2(c_1,q_2c_2,\rho^*)-\phi(q_2c_2)BCF(c_1,q_2c_2,\rho^*)}{[\Phi(q_2c_2)]^2}q_2\beta_2^w$$

with

(C10) $$g_1(c_1,q_2c_2,\rho^*) = \frac{\partial BCF(c_1,q_2c_2,\rho^*)}{\partial c_1} = \phi(c_1)\,\Phi\left[\frac{q_2c_2-\rho^*c_1}{\sqrt{1-(\rho^*)^2}}\right]$$

(C11) $$g_2(c_1,q_2c_2,\rho^*) = \frac{\partial BCF(c_1,q_2c_2,\rho^*)}{\partial (q_2c_2)} = \phi(q_2c_2)\,\Phi\left[\frac{c_1-\rho^*q_2c_2}{\sqrt{1-(\rho^*)^2}}\right]$$

(C12) $$c_1 = \begin{cases} c_1^1 = \beta_1'x_1 + \gamma & when\ y_2 = 1 \\ c_1^0 = \beta_1'x_1 & when\ y_2 = 0 \end{cases}$$

Φ and ϕ are the univariate Normal cumulative and density functions, respectively.

Finally, the unconditional probability is

(C13) $$p[y_1 = 1|x_1,x_2] = p[y_2 = 1|x_2] * p[y_1 = 1|y_2 = 1,x_1,x_2] + p[y_2 = 0|x_2] * p[y_1 = 1|y_2 = 0,x_1,x_2] = \Phi(c_2) * p[y_1 = 1|y_2 = 1,x_1,x_2] + \Phi(-c_2) * p[y_1 = 1|y_2 = 0,x_1,x_2]$$

and the corresponding marginal effect is:

(C14) $$\frac{\partial p[y_1=1|x_1,x_2]}{\partial w} = \left\{\Phi(c_2)\frac{\partial p[y_1=1|y_2=1,x_1,x_2]}{\partial w} + \Phi(-c_2)\frac{\partial p[y_1=1|y_2=0,x_1,x_2]}{\partial w}\right\} + \{\phi(c_2)p[y_1 = 1|y_2 = 1,x_1,x_2] - \phi(c_2)p[y_1 = 1|y_2 = 0,x_1,x_2]\}$$

By substituting (3), (6), (7) and (8) in (10) we get the sum of a direct and an indirect effect[1]

(C15) $$\frac{\partial p[y_1=1|x_1,x_2]}{\partial w} = [g_1(c_1^1,c_2,\rho) + g_1(c_1^0,-c_2,-\rho)]\beta_1^w + \left\{\frac{g_2(c_1^1,c_2,\rho)}{\Phi(c_2)} + \frac{g_2(c_1^0,-c_2,-\rho)}{\Phi(-c_2)}\right\}\beta_2^w$$

When $\rho = 0$, it is also verified that $p[y_1 = 1|x_1,x_2] = \Phi(c_1)$, $g_1(c_1^1,c_2,\rho) = \phi(c_1^1)\,\Phi(c_2)$, $g_1(c_1^0,-c_2,-\rho) = \phi(c_1^0)\,\Phi(-c_2)$, $g_2(c_1^1,c_2,\rho) = \phi(c_2)\,\Phi(c_1^1)$ and $g_2(c_1^0,-c_2,-\rho) = \phi(-c_2)\,\Phi(c_1^0)$, given the symmetry of the normal distribution. Thus, the marginal effect (C15) for the continuous covariate is

(C16) $$\frac{\partial p[y_1=1|x_1,x_2]}{\partial w} = [\phi(c_1^1) + \phi(c_1^0)]\beta_1^w + [\phi(c_2)\Phi(c_1^1) + \phi(-c_2)\Phi(c_1^0)]\beta_2^w$$

We now consider a model where the first equation is modelled through an ordered probit (Model 2). More precisely, we admit that the observed discrete variable of the first equation can assume three possible values:

(C17) $$y_1 = \begin{cases} 0 & if\ y_1^* \le cut1 \\ 1 & if\ cut1 < y_1^* \le cut2 \\ 2 & if\ y_1^* > cut2 \end{cases}$$

[1] In this case, it is true that $\Phi(-c_2) = 1 - \Phi(c_2)$ and $\phi(c_2) = \phi(-c_2)$.

The second equation is the same as before. In this case, the marginal effect can be calculated using a similar approach and it can be explicitly written as:

(C18) $$\frac{\partial p[y_1=j|x_1,x_2]}{\partial w} = \left\{\Phi(c_2)\frac{\partial p[y_1=j|y_2=1,x_1,x_2]}{\partial w} + \Phi(-c_2)\frac{\partial p[y_1=j|y_2=0,x_1,x_2]}{\partial w}\right\} + \{\phi(c_2)p[y_1 = j|y_2 = 1, x_1, x_2] + \phi(-c_2)p[y_1 = j|y_2 = 0, x_1, x_2]\}$$

with $j = 0,1,2$ and

(C19) $$p[y_1 = j|y_2, x_1, x_2] = \frac{\Psi(c_1,c_2,\rho^*)}{\Phi(q_2c_2)}$$

(C20) $$\Psi(c_1, c_2, \rho^*) = \begin{cases} BCF(cut1 - c_1, q_2c_2, -\rho^*) & if\ j = 0 \\ BCF(cut2 - c_1, q_2c_2, -\rho^*) - BCF(cut1 - c_1, q_2c_2, -\rho^*) & if\ j = 1 \\ BCF(-cut2 + c_1, q_2c_2, \rho^*) & if\ j = 2 \end{cases}$$

and the derivative is given by (14), with

(C21) $$g_1(c_1, q_2c_2, \rho^*) = \frac{\partial\Psi(c_1,q_2c_2,\rho^*)}{\partial c_1}$$

$$= \begin{cases} \phi(cut1 - c_1)\Phi\left[\frac{q_2c_2 + \rho^*(cut1 - c_1)}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 0 \\ \phi(cut2 - c_1)\Phi\left[\frac{q_2c_2 + \rho^*(cut2 - c_1)}{\sqrt{1-(\rho^*)^2}}\right] - \phi(cut1 - c_1)\Phi\left[\frac{q_2c_2 + \rho^*(cut1 - c_1)}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 1 \\ \phi(-cut2 + c_1)\Phi\left[\frac{q_2c_2 - \rho^*(-cut2 + c_1)}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 2 \end{cases}$$

and

(C22) $$g_2(c_1, q_2c_2, \rho^*) = \frac{\partial\Psi(c_1,q_2c_2,\rho^*)}{\partial(q_2c_2)}$$

$$= \begin{cases} \phi(q_2c_2)\Phi\left[\frac{cut1 - c_1 + \rho^*q_2c_2}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 0 \\ \phi(q_2c_2)\Phi\left[\frac{cut2 - c_1 + \rho^*q_2c_2}{\sqrt{1-(\rho^*)^2}}\right] - \phi(c_2)\Phi\left[\frac{cut1 - c_1 + \rho^*q_2c_2}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 1 \\ \phi(q_2c_2)\Phi\left[\frac{-cut2 + c_1 - \rho^*q_2c_2}{\sqrt{1-(\rho^*)^2}}\right] & if\ j = 2 \end{cases}$$

Thus, the marginal effect of the unconditional probability is obtained using (12), (20) and (21).

When $\rho = 0$, it is shown that (19), (20) and (21) are as follows:

(C23) $$\Psi(c_1, c_2, \rho^*) = \begin{cases} \Phi(q_2c_2)\ \Phi(cut1 - c_1) & if\ j = 0 \\ \Phi(q_2c_2)[\Phi(cut2 - c_1) - \Phi(cut1 - c_1)] & if\ j = 1 \\ \Phi(q_2c_2)\ \Phi(-cut2 + c_1) & if\ j = 2 \end{cases}$$

(C24) $$g_1(c_1, q_2c_2) = \begin{cases} \phi(cut1 - c_1)\Phi(q_2c_2) & if\ j = 0 \\ \phi(cut2 - c_1)\Phi(q_2c_2) - \phi(cut1 - c_1)\Phi(q_2c_2) & if\ j = 1 \\ \phi(-cut2 + c_1)\Phi(q_2c_2) & if\ j = 2 \end{cases}$$

(C25) $$g_2(c_1, q_2c_2) = \begin{cases} \phi(q_2c_2)\Phi(cut1 - c_1) & if\ j = 0 \\ \phi(q_2c_2)[\Phi(cut2 - c_1) - \Phi(cut1 - c_1)] & if\ j = 1 \\ \phi(q_2c_2)\Phi(-cut2 + c_1) & if\ j = 2 \end{cases}$$

Tables

Table 1. Exporting propensity, firm's heterogeneity and eco-innovation induced by regulation (Coefficients Estimate, Model 1)

	Germany		**East European Countries**	
	All sample	*Innovators*	*All sample*	*Innovators*
dEXP				
dEnvInno	0.268*	0.137	-0.215	-0.233
	(0.141)	(0.157)	(0.276)	(0.278)
Prod	0.392***	0.404***	0.256***	0.254***
	(0.039)	(0.042)	(0.033)	(0.032)
dmedium	-0.018	-0.061	0.321***	0.321***
	(0.098)	(0.104)	(0.093)	(0.093)
dlarge	-0.449**.	-0.495**	0.511***	0.516***
	(0.185)	(0.194)	(0.163)	(0.163)
constant	0.987***	1.021***	0.559**	0.572**
	(0.209)	(0.226)	(0.278)	(0.279)
dEnvInno				
CoAll	0.083	0.0.072		
	(0.079)	(0.080)		
Rd	0.581***	0.256***		
	(0.087)	(0.094)		
Reput			0.572***	0.567***
			(0.068)	(0.097)
rdExp			0.124	0.116
			(0.114)	(0.112)
Prod	0.098***	0.100***	0.103***	0.102***
	(0.034)	(0.036)	(0.029)	(0.029)
dmedium	0.088	0.050	-0.121	-0.124
	(0.096)	(0.100)	(0.087)	(0.136)
dlarge	0.321*	0.248	-0.151	-0.140
	(0.170)	(0.179)	(0.135)	(0.137)
constant	-0.996***	-0.642***	0.106	0.110
	(0.221)	(0.233)	(0.201)	(0.201)
N. of Observations	2987	2318	18951	5553
Log Likelihood	-2059.47	-1860.49	-1880.55	-1864.82
Wald Chi2	772.33***	571.59***	439.09***	430.80***

*Note: Significance levels: *** 0.01, ** 0.05, * 0.1. Sectors dummies are statistically significant, but they are not reported but they are available upon request.*

Table 2. Exporting propensity, firm's heterogeneity and eco-innovation induced by regulation (Marginal Effects - Model 1)

		Germany		East European Countries	
		All sample	*Innovators*	*All sample*	*Innovators*
dEXP					
dEnvInno		0.067**	0.034**	-0.035	-0.038
		(0.032)	(0.016)	(0.025)	(0.027)
Prod					
	Direct effect	0.198**	0.199**	0.084	0.083
		(0.093)	(0.096)	(0.059)	(0.058)
	Indirect effect	0.028**	0.064***	0.048	0.046
		(0.013)	(0.024)	(0.032)	(0.031)
	Total	0.250***	0.254***	0.129*	0.126*
		(0.087)	(0.091)	(0.068)	(0.067)
Medium/Large Firm					
	dEnvInno=1	0.026	0.001	0.053	0.056
		(0.048)	(0.052)	(0.050)	(0.050)
	dEnvInno=0	-0.117***	-0.105**	0.040	0.037
		(0.039)	(0.042)	(0.032)	(0.031)
	Total	-0.091*	-0.103*	0.093*	0.093*
		(0.052)	(0.062)	(0.051)	(0.051)

*Note: Significance levels: *** 0.01, ** 0.05, * 0.1*

Table 3. Destination markets and eco-innovation induced by regulation - Descriptive frequencies and percentages

	Germany				East European Countries			
	EXP							
dEnvInno	*0*	*1*	*2*	**Total**	*0*	*1*	*2*	**Total**
0	406	211	496	1113	60	158	271	489
1	243	197	623	1063	273	607	1154	2034
missing	160	112	441	713	6761	5714	3389	15864
Total	809	520	1560	**2889**	7094	6479	4814	**18387**
0	14,05%	7,30%	17,17%	38,53%	0,33%	0,86%	1,47%	2,66%
1	8,41%	6,82%	21,56%	36,79%	1,48%	3,30%	6,28%	11,06%
missing	5,54%	3,88%	15,26%	24,68%	36,77%	31,08%	18,43%	86,28%
Total	28,00%	18,00%	54,00%	**100%**	38,58%	35,24%	26,18%	**100%**

Table 4. Destination markets, firm's heterogeneity and eco-innovation induced by regulation (Marginal Effects - Model 2)

	Germany				**East European Countries**			
	All sample		*Innovators*		*All sample*		*Innovators*	
	Exporter 1	Exporter 2	Exporter 1	Exporter 2	Exporter 1	Exporter 2	Exporter 1	Exporter 2
EXP								
dEnvInno	-0.004	0.033***	0.001	-0.009***	0.029	-0.062***	0.030	-0.063***
	(0.012)	(0.010)	(0.003)	(0.003)	(0.021)	(0.015)	(0.021)	(0.015)
Prod								
Direct effect	0.027	0.202***	0.034	0.206***	0.073	0.154***	0.073	0.154***
	(0.072)	(0.064)	(0.070)	(0.064)	(0.051)	(0.037)	(0.050)	(0.037)
Indirect effect	0.016**	0.045*	0.017	0.051**	0.017	0.029	0.016	0.028
	(0.008)	(0.027)	(0.008)	(0.026)	(0.014)	(0.021)	(0.014)	(0.021)
Total	0.048	0.247***	0.058	0.255***	0.091**	0.182***	0.091**	0.181***
	(0.070)	(0.072)	(0.065)	(0.071)	(0.045)	(0.045)	(0.045)	(0.045)
Medium/Large Firms								
dEnvInno=1	0.021**	0.025	0.020*	0.008	-0.086**	0.149***	-0.086**	0.151***
	(0.010)	(0.028)	(0.011)	(0.025)	(0.042)	(0.048)	(0.042)	(0.047)
dEnvInno=0	-0.017**	-0.043*	-0.013**	-0.038**	0.008	0.019*	0.007	0.018*
	(0.008)	(0.025)	(0.006)	(0.019)	(0.006)	(0.011)	(0.006)	(0.010
Total	0.004	-0.019	0.007	-0.030*	-0.078*	0.168***	-0.078*	0.169***
	(0.008)	(0.015)	(0.012)	(0.016)	(0.046)	(0.042)	(0.046)	(0.041)
N. obs	2889		2233		18387		5442	
Log Likelihood	-2812.37		-2555.89		-3143.94		-3125.16	
Wald chi2	918.66***		706.72***		702.20***		691.41***	
Cut-point 1	-0.654***		-0.634***		-1.276***		-1.282***	
	(0.205)		(0.217)		(0.244)		(0.246)	
Cut-point 2	0.010		0.025		-0.136		-0.140	
	(0.205)		(0.216)		(0.241)		(0.242)	

*Note. Significance levels: *** 0.01, ** 0.05, * 0.1*