Pollution Haven Effect and Porter Hypothesis: Is firm heterogeneity a driver for environmental tax, eco-innovation and export relationship?

Silvia Bertarelli [1] and Chiara Lodi [2, *]

[1,2] University of Ferrara—Department of Economics and Management; Via Voltapaletto, 11 - 44121 Ferrara, Italy
* Corresponding Author: chiara.lodi@unife.it; Tel.: +39-0532-455065, Fax.: +39-0532-245951

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Abstract: The effect of environmental policies on innovation adoption and firm performance has been widely studied for the last decades and many controversial results have been obtained. This paper tries to shed light on the relationship among environmental regulation, eco-innovation and trade performance by theoretically and empirically investigating the role of productivity heterogeneity at firm level. On the basis of an international trade model with monopolistic competition, we have obtained some theoretical predictions that identify whether and under what conditions a firm will export or not and which technology to be adopted. Then, theoretical predictions are tested on CIS2008 and CIS2014 datasets. Estimates underline that environmental regulations foster eco-innovation adoption but lower exporting propensity of firms, especially in brown sector firms. Furthermore, being an eco-innovator enhances the propensity of being also an exporter. This result is stronger the more productive firms are.

Keywords: Firm heterogeneity; Pollution Haven Effect; Porter Hypothesis; Eco-innovation; Exporting propensity; German firms

JEL: F12, F18, Q55

1. Introduction

In the last twenty years, innovation and environmental issues have captured the international authorities' attention, especially in a context where globalization, has played a crucial role in competitiveness improvement and sustainable growth. It is important to understand that the relationship among all these aspects is complex and economists have obtained controversial results. Since firms could differently react and adapt to complexity, the present work aims at theoretically and empirically studying the role of productivity heterogeneity across firms as a crucial driver of technology adoption and exporting decisions in the presence of eco-regulation. By studying a firm's exporting decision in the Melitz (2003) trade model where technology can be either dirty or green, some theoretical predictions are shown and econometrically tested. Specifically, they include a negative direct impact of environmental regulation on exporting propensity and a positive effect of regulation on innovation. Moreover, the indirect impact of regulation on trade performance through innovation decisions can be measured. The econometric strategy based on the Endogenous Switching Model accounts for the dichotomous nature of export and innovation variables and the possible endogeneity of eco-innovation covariates, with reference to CIS2008 and CIS2014 manufacturing German firms.

This paper is closely related to different contributions of the existing debate on trade, innovation and environment aspects. First, we refer to macro and micro trade theories that have studied the link between innovation and exporting [Grossman and Helpman (1991), Yeaple (2005), Piccardo et al. (2013), Bustos (2011), and Tavassoli (2013)]. This literature has predicted a positive bidirectional relation, especially at firm level. A second strand of the literature concerns the impact of innovation on emissions. A huge number of works has pointed out the positive effect of innovation in diminishing environmental pollution and in preserving natural resources. In this process, governments play a fundamental role in leading countries toward a sustainable change by introducing well-designed regulations that foster innovation adoption and structural changes. Third, this paper is also connected to the literature analyzing the effect of environmental policies on eco-innovation adoption and diffusion processes, whose results are controversial. On one side, green regulations, or more stringent ones, generate higher compliance costs of production, worsening firms' competitiveness [Tobey (1990), Grossman and Krueger (1991), Copeland and Taylor (2004)]. On the other side, some theoretical and empirical works have demonstrated that these regulations are fundamental for the adoption of abatement technologies [Milliman and Prince (1989), Jung et al. (1996), Horbach (2008) and Horbach et al. (2012)]. Furthermore, at micro level, several studies have argued that environmental regulation not only causes higher costs but, these costs, are accompanied by an improvement in economic and environmental performance, which is driven by innovation [Porter

(1991), Porter and Van Der Linde (1995)]. Finally, the work is especially related to an emerging empirical and theoretical literature that accounts for firms' heterogeneity when international trade and environmental issues are debated [Kreickemeier and Ritcher (2014), Cao et al. (2016), Holladay (2016), Cui et al. (2017) and Forslid et al. (2018)]. Specifically, these studies introduce innovation decisions into the heterogeneous framework of Melitz (2003) and share a common result. The most productive firms introduce an abatement technology and serve both domestic and foreign markets. Cao et al. (2016) explore inverted U-shaped curves for investments in abatement technology for a panel of Chinese firms. Holladay (2016) has empirically analyzed the effect of export orientation and import competition on emissions using US establishment data, with reference to the theoretical framework of Cui et al. (2017).

The paper contribution is many folds. First, though the Melitz framework has been frequently used in environmental studies, our objective is different. We aim at understanding whether productivity heterogeneity at firm level plays a relevant role in explaining controversial results about the effect of eco policies on trade and innovation decisions. Differently, Kreickemeier and Ritcher (2014), have studied the effect of trade liberalization on aggregate emissions at country level. Forslid et. al. (2018) have analyzed which is the role of endogenous abatement investments into trade and emissions dynamics at industry level. Second, we have tested our prediction on German manufacturing firms, since Germany plays an important role in the definition of European Union policies and represents one of the most advanced economies in the European scenario, especially when environmental protection and eco-innovation investments are considered.

Third, no empirical studies have implemented CIS data for testing environmental and trade performances in Melitz (2003) approach for explaining. By using this type of data, our work can exploit useful information about environmental aspects, especially related to innovation. Furthermore, among the literature on environmental policies and trade, Van Leeuwen and Mohnen (2017) and Rammer et al. (2017) only, have analysed the effect of environmental regulations, specifically energy ones, on exporting propensity of firms by implementing CIS dataset, but they have used a single dataset (either 2008 or 2014 release). Differently, the present analysis is conducted by comparing CIS2008 and more recent CIS2014 samples from Eurostat. These datasets cover different time periods, a pre-economic crisis period (2006-2008) and an after crisis one (2012-2014). By considering both periods, we can analyze the importance of eco-innovation and environmental regulations on firms' exporting decision in time periods where economic priorities were different.

The remainder of the paper is organized as follows. Section 2 provides the literature review on environmental policies, eco-innovation and trade performance. In Section 3 and 4, description of the theoretical framework and the econometric model are proposed. Section 5 reports data description and Section 6 the results. In Section 7, a robustness analysis is conducted by estimating the effect of environmental tax on small, medium and large firms' propensity of exporting and innovating. Section 8 concludes.

2. Literature Review

For the last thirty years, many researchers have been investigating the relationship between environmental regulation and innovation, between regulation and economic performance, and among these aspects all together. Considering the aim of the research, our approach essentially refers to four strands of literature. A first strand of the literature concerns the theoretical models on partial equilibrium analysis of different environmental policies as incentives for innovation adoption[1]. Specifically, our work is strictly related to models that assume an *ex ante* and myopic regulator [Milliman and Prince (1989) and Jung et al. (1996)], so it is supposed that the regulator moves as the first player, with respect to firms, and does not anticipate the new technology. These works have demonstrated that taxation produces higher savings than other types of environmental policies, thus it has the strongest impact on technology decision at firm level. The second strand of literature is developed within the neoclassical framework and argues that competitiveness may be harmed by the introduction of an environmental regulation, or by a higher stringency of an existing one, due to an

[1] For a detailed survey on theoretical models with environmental policy incentives for innovation see Requate (2005).

increase of production costs, named *compliance costs*[2]. The negative effect of a tight pollution regulation on production costs and, consequently, on competitiveness, thus on comparative advantage and trade, is well-known as *Pollution Haven Effect*. Specifically, it states that, a more stringent environmental policy increases the costs of production and, consequently, a loss of competitiveness occurs for a given level of trade barriers. This situation entails a decrease of net exports and incoming foreign direct investments for sectors affected by regulation (polluting sectors). The *Pollution Haven Effect* is a fundamental driver of the *Pollution Haven Hypothesis*, which underlines that trade liberalization can induce a reallocation of commodities' production: more polluting industries or firms move toward countries with less stringent environmental regulation [Copeland and Taylor (2004)]. In other words, the *Pollution Haven Effect* is a necessary, but not sufficient, condition for having *Pollution Haven Hypothesis*. It becomes sufficient when it dominates the other sources of comparative advantage or these sources are absent [Taylor (2005), Cherniwchan et al. (2016)]. Nowadays, recent theoretical and empirical studies have supported the *Pollution Haven Effect*[3]. On the contrary, the evidence about the *Pollution Haven Hypothesis* still remain less robust since it underlines different results and it is theoretically contrasted by a higher relevance of other factors of comparative advantage other than environmental regulation in conditioning trade flows, such as factor endowments and technological differences [Copeland and Taylor (1994)]. Researches about Pollution Havens have been especially conducted at macro level and they can be divided into two waves. A first wave of studies argues that tighter environmental policies have a small effect on trade, even insignificant. For example, Tobey (1990), by empirically testing an extended version of the Heckscher-Ohlin-Vanek (HOV) model of international trade[4], finds that dirty industries' localization

[2] At firm level, these costs bring to the adaptation of production processes or to a rethinking of the organization.

[3] See Jaffe et al. (1995), Copeland-Taylor (2004) and Taylor (2005) for a review of the *Pollution Haven Effect*.

[4] Tobey (1990) extends the Heckscher-Ohlin-Vanek model of international trade by including a qualitative measure of environmental regulation stringency.

and trade patterns are not affected by the intensity of environmental regulation. Furthermore, Grossman and Krueger (1993), who investigate the determinant of Mexican trade flows, suggest that labour endowments represent a more relevant source of comparative advantage than environmental regulation. A second wave of studies underlines that previous results are preliminary and weak because of four drawbacks. First, results are strictly affected by the quality of data and the level of analysis. Van Beers and Van Den Berg (2000), by revising the gravity model of Tobey (1990) and applying it at a more disaggregated level and for different industries, find that environmental policy stringency has a positive and significant effect on exports, especially for paper sector, but this effect is not confirmed for all dirty industries (chemicals and steel). Second, focussing on gravity estimates of the effect of environmental policy stringency on trade flows, the econometric model and the corresponding assumptions are very important. Ederington and Minier (2003), by modelling environmental regulation as an endogenous variable, show that the intensity of environmental policy has a strong effect on net imports (scaled by domestic production). Furthermore, Jug and Mirza (2005), by using different data sourced by Eurostat and implementing a gravity model that admits endogeneity and measurement errors, find a negative and significant relationship between regulation and relative imports. Third, cross-country and sector heterogeneity plays a relevant role in explaining the impact of pollution policies on trade. Harris et al. (2002), construct a three-dimension gravity model that accounts for importing, exporting and time effects and they do not find any significant impact of six different environmental regulation intensity measures on net imports, but they point out that it is fundamental to consider import, export and time fixed effects to account for heterogeneity. Mulatu et al. (2003), by examining the effect of environmental abatement costs on net exports of manufacturing industry in three different countries (United States, Germany and Netherland), show that results differ across countries and sectors. Specifically, a tighten environmental policy, which requires higher capital expenditure, represents a source of comparative advantage for polluting industries in the United States, while an increase of environmental costs negatively affects the net value of exports on total value of production of polluting-intensive sectors in Germany and

Netherland. Ederington et al. (2005), who adopt pollution abatement costs as a measure of environmental regulation and net imports scaled by shipments as a measure of trade variable costs, confirm the importance of heterogeneity across industries in studying the trade-environment relationship. In other words, if we do not consider the peculiarities of each sector, we will understate the effect of the pollution policy on trade. Finally, one of the most important reasons that explain the above-mentioned divergent results is related to the measure of environmental regulation. Tsurumi et al. (2015) study the impact of three different measures of environmental policy stringency (energy intensity, abatement costs intensity, survey indices) on bilateral trade flows. The paper shows that an increase in abatement costs brings a decrease of both net exports and GDP, but energy intensities and survey indices boost trade flows.

In general, it is possible to state that environmental regulation significantly affects trade, but the sign and the magnitude of the effect could be different.

A third important part of literature is based on the *Porter Hypothesis*, which aims at demonstrating the positive effect of environmental regulation on innovation and, as a consequence, on competitiveness of firms and the market as a whole. Specifically, following the idea of Porter (1991) and Porter and Van der Linde (1995), Jaffe and Palmer (1997) has underlined three versions of this hypothesis. The *weak* Porter Hypothesis suggests that a more stringent environmental regulation, such as a command-and-control policy[5], affects "certain types" of innovation, mainly eco-innovation, but do not completely offset compliance costs. The *narrow* Porter Hypothesis points out the relevance of environmental policies that stimulate environmental innovation, specifically, Porter and Van der Linde argue that more flexible environmental policies have a higher impact on the adoption of innovation than command-and-control regulations. Furthermore, these regulations also stimulate firms' competitiveness. Finally, the third type is the *strong* Porter Hypothesis. This hypothesis allows

[5] Command-and-Control environmental regulations impose specific limits for pollution emission or the implementation of specific abatement technologies.

a dynamic mechanism to evaluate the effect of environmental regulation on innovation and, in turn, on economic and environmental performance. Following this version of the Porter Hypothesis, a "well-designed" environmental policy could represent an opportunity for firms: if the innovation is induced by the introduction of environmental regulation, it could generate benefits that more than compensate compliance costs, thus implying an increase in firm's competitiveness. In other words, a green policy should encourage firms to innovate and to reorganize their production in a more efficient way. This mechanism could be advantageous both socially and economically.

For the last twenty years, a huge number of researches have been empirically studying all versions of the Porter Hypothesis[6]. Concerning the *weak* Porter Hypothesis, applied researchers commonly agree on a significant and positive impact of environmental policy on eco-innovation by using different measures of environmental innovation and environmental regulation[7]. This version of the Porter Hypothesis is in line with neoclassical theoretical model that study the environmental policy incentives in adopting abatement technology. By focusing on *narrow* Porter hypothesis, a few studies have been conducted. For example, by studying the effect of environmental regulation and innovation on trade volumes in the manufacturing industry, Costantini and Mazzanti (2012) empirically show that regulation, through a positive effect on innovation, indirectly increases the competitiveness of eco-friendly industries. Furthermore, Lanoie et al. (2011) support the *narrow* Porter Hypothesis by finding that a flexible environmental policy, such as performance-based standards, has a positive effect on innovation. Finally, the most studied version of the Porter Hypothesis is the *strong* one, both at micro and macro level. Results are contrasting and depend on different aspects, such as how firms'

[6] For a good review of the literature we refer to Ambec et al. (2013). Furthermore, Cohen and Tubb (2017) make a meta-analysis on the Porter Hypothesis.

[7] Brunnermeier and Cohen (2003), Lanoie et al. (2011), Rubashkina et al. (2015), Franco and Marin (2017) and Van Leeuwen and Mohnen (2017).

competitiveness[8], environmental regulation, environmental innovation are measured[9]. In the literature about the *strong* Porter Hypothesis, a small number of studies have been focused on the connection between trade and environment. Costantini and Mazzanti (2012), who conduct an industry-level analysis across EU15 countries, support this hypothesis by concluding that environmental regulations positively and significantly affect innovation and European Union competitiveness by boosting exports. Conversely, Rammer et al. (2017), focusing on German, Swiss and Austrian firms, do not confirm the *strong* Porter hypothesis mechanism by studying the impact of energy policies on firms' exports and market position.

Finally, a fourth strand of the literature is connected to international trade theory that underlines a positive relationship between innovation and exporting performance. In 2005, Yeaple, by focusing on a general equilibrium trade model with homogeneous firms, has shown that in the presence of fixed costs associated with both technology adoption and exporting, only those firms that adopt advanced technologies start to export. Similarly, Bustos (2011) has suggested that trade liberalization can stimulate upgraded technology adoption by using a model with heterogeneous firms where the choice of technology is jointly modeled with production and export decisions. Models like Bustos (2011), that refer to Melitz's model of 2003, have been highly used in order to study the relationship between different environmental aspects and trade. For example, Kreickermeier and Richter (2014) have identified a fourth effect of trade on environmental emissions, the reallocation effect, which states that international integration increases average productivity and, subsequently, reduces the emission intensity. Nevertheless, there is another (scale) effect that causes an increase of emissions,

[8] See Dechezleprêtre and Sato (2014) for a review on the impact of environmental regulations on firms' competitiveness measured by trade, employment, productivity and innovation activities.

[9] Lanoie et al. (2011), Broberg et al. (2013), Rexhäuser and Rammer (2014) and Rubashkina et al. (2015) find no evidence of the strong Porter Hypothesis, whereas Lanoie et al. (2008), Albrizio et al. (2017) and Marin and Franco (2017) support it.

so the net effect will be positive if and only if the emission intensity of firms strongly decreases. Moreover, Forslid et al. (2018) have constructed a theoretical model following Melitz (2003) in order to understand, through the abatement technology investments mechanism, if exporters have lower level of emissions due to the introduction of an environmental tax. They further investigate the effect of trade liberalization on aggregate level of emissions. Their investigation has shown that trade liberalization increases production and exporting firms become cleaner than non-exporting ones because they are induced to invest in abatement technologies.

By using the same approach of these studies, in the next section we describe the theoretical model.

3. Theoretical Framework

In this section, a theoretical model based on Melitz (2003) and Bustos (2011) is developed to allow some predictions - to be empirically tested - on the impact of environmental taxation and investment in abatement technology on export propensity at firm level. The basic framework entails international trade and heterogeneous firms where manufacturing of goods produces pollution. First, firms make the decision to invest in an abatement technology to reduce emissions or not. Then they choose to serve either the domestic market or the domestic and export markets. Firms pay an emission tax for pollution and trade costs for foreign sales. Some additional fixed costs of entry in domestic and export markets are to be paid by firms implying decreasing average costs.

Demand: consumers' preferences are described by a CES utility function. The demand function for variety j with constant elasticity of substitution ε, with $\varepsilon > 1$, is $X_j = Ap_j^{-\varepsilon}$, where A denotes aggregate expenditure for differentiated products, which is exogenous at firm level and endogenous for the industry; p_j is variety j's price.

Entry and production: each firm will produce a differentiated product to be supplied in a monopolistically competitive market using only one factor, labor, given an inelastic labor supply L at the aggregate level. Firms are heterogeneous in their productivity for a given technology and draw a productivity φ from a cumulative probability distribution function G(φ) when a fixed entry cost f_e, expressed in units of labor, is paid. The cost function exhibits constant marginal cost with a fixed cost. However, marginal and fixed costs differ when selling to domestic customers from those to be paid to reach foreign customers when the world economy is imperfectly integrated.

Technology: we assume that one unit of pollution is emitted for each unit of output for all varieties, thereby each firm will decide to adopt an emission abatement technology or not. In the former situation, we refer to clean-type firms, in the latter one to dirty-type firms. We say that a dirty-type technology is a baseline or low-level technology, while a clean-type one is an upgraded technology. A dirty-type technology entails a Pigouvian tax for each unit of pollution, while the clean-type technology is able to completely abate pollutants, for simplicity, and asks for higher fixed costs and lower variable costs than the dirty-type one. Our model differs from Copeland and Taylor (1994) for some aspects. They have proposed a general equilibrium model with the aim of interpreting the role of comparative advantage factors and environmental emissions at country level, while our objective is to study the role of firms' heterogeneity in the regulation, innovation and trade mechanism. They consider two sectors that differ in pollution and factor intensity, in the presence of two factors of production (capital and labor). We instead concentrate on a more simplified framework that includes only one factor of production (labor) and we assume that firms can choose between abating all emitted pollution, by using clean-type technology, or do not abate at all and pay a tax. Furthermore, their work implements an endogenous regulation, while we hypothesize that the environmental tax is exogenous because the model is micro and firms take the tax as given. Our simplification allows to pay more attention on the choice of technology and to analyze firms' differences in terms of innovation.

Firm's decision: we analyze firm j's decisions of whether to enter the export market and whether to adopt technology m, where $= d, c$; subscripts d and c indicate dirty-type and clean-type technologies, respectively. We compare total profits for the two alternative technologies when the pricing rule of a fixed mark-up over marginal costs is set. In the presence of CES consumers' preferences, we can easily calculate (domestic) profits for any non-exporter with an ex-ante productivity level φ and using a technology m as follows (j subscript suppressed to simplify notation):

(1) $$\pi_m^d = A\left(\frac{c_m}{\alpha\varphi}\right)^{1-\varepsilon}(1-\alpha) - f_m \qquad\qquad m = d, c$$

where a dirty-type firm's marginal cost is $c_d = c(1+t)$. The marginal cost includes an *ad valorem* environmental tax since pollution cannot be abated. Differently, a clean-type firm's marginal cost is c_c, with $c_c < c$, assuming that pollution is totally abated. Profits also depend on industry expenditure A, and fixed costs of production, f_d or f_c, with $f_c > f_d$.

In the presence of variable (iceberg) trade costs τ, with $\tau > 1$, a firm can get additional variable profits by selling to foreign customers. However, fixed costs of exporting f_m^* are to be paid. For any exporter and for a given technology m the corresponding profit from export sales is

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

Following Melitz (2003), we can easily show that the higher is productivity φ the higher are domestic and export profits. We calculate cut-off productivity levels when a zero-profit condition is imposed in (1) and (2). Domestic and foreign cut-offs for dirty-type firms are

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

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

and for clean-type firms are the following

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

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

Then we can identify three groups of non-active firms, non-exporters, and exporters for each technology. The domestic cut-off *DD* (*CD*) identifies the lowest productivity level for successful entry when a dirty (clean) technology is chosen. Analogously, the foreign cut-off *DF* (*CF*) relates to a dirty-type (clean-type) marginal productivity level to get non-negative foreign profits. A dirty-type (clean-type) firm producing for the domestic market will have an ex-ante productivity level φ, which is higher than *DD* (*CD*) but lower than *DF* (*CF*). With $\varphi > DF$ ($\varphi > CF$), firms will sell to domestic and foreign customers. The partitioning of firms will occur whenever $\tau^{\varepsilon-1}\frac{f_m^*}{f_m} > 1$, with $m = d, c$. So that $DF > DD$ ($CF > CD$).

Finally, we compare dirty-type and clean-type firm's profits to evaluate *j* firm's innovation decision. We assume that $\frac{f_c}{f_c^*} > \frac{f_d}{f_d^*}$, thus domestic initial fixed of clean-type technology is higher than dirty-type technology given similar foreign fixed costs. As for non-exporter, we can show that using the clean technology is always dominated by the dirty technology when $CD > DD$, which occurs when the environmental tax is not too high, or $(1+t) < \frac{c_c}{c}\left[\frac{f_c}{f_d}\right]^{\frac{1}{\varepsilon-1}} = T1$. When firms export, some of them will use dirty technology and other ones will use clean technology. In this case, what is labelled by Bustos (2011) an adoption productivity cut-off $\tilde{\varphi}$ - such that $\pi_d^d + \pi_d^* = \pi_c^d + \pi_c^*$ - must be greater than DF. The adoption cut-off is the following

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

The condition for which $\tilde{\varphi} > DF$ is $(1+t) < \frac{c_c}{c}\left[1+\frac{f_c+f_c^*-f_d-f_d^*}{(1+\tau^{\varepsilon-1})f_d^*}\right]^{\frac{1}{\varepsilon-1}} = T2$. In the opposite case, all exporters will adopt the clean technology. However, the latter case is not empirically supported by CIS data.

When $T1 > T2$, we can obtain three possible scenarios. The first, where the environmental tax could guarantee the coexistence between dirty-type and clean-type exporters, is verified when $(1+t) < T2 < T1$. The second scenario, that underlines the existence of clean-type exporters only, is guaranteed if $T2 < (1+t) < T1$ and the third one, where dirty-type firms disappear and both domestic and foreign markets are supplied by clean-type firms, when $T1 < (1+t)$[10].

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 $\bar{\pi}$ and the productivity cut-off *DD* as follows

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

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 for which the net value of entry is equal to zero indicates a positive correlation between the industry average profit and the productivity cut-off *DD*. Given a discounting factor δ and the fixed entry cost f_e we have

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

By combining (8) and (9) we can determine a unique domestic cut-off *DD* and average profit $\bar{\pi}$ such that the industry is in equilibrium. In turn, we can obtain the equilibrium export cut-off *DF* and the adoption cut-off $\tilde{\varphi}$, from (4) and (7) respectively[11].

The impact of environmental regulation: we study the effect of an increase of the environmental tax t on *DD*, *DF* and $\tilde{\varphi}$. We can show that domestic and export cut-offs for dirty-type firms 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, the adoption cut-off will decrease so it is convenient for some intermediate productive exporters to switch from the dirty technology to the clean one[12].

[10] If $T1 < T2$, there is only one environmental tax range for which dirty-type and clean-type firms export and it corresponds to $(1+t) < T1 < T2$. If this condition is not satisfied, dirty-type firms disappear and markets are supplied by clean-type firms only.

[11] The analysis of industry equilibrium is detailed in Appendix B.

[12] See the Appendix for formal proofs

Summary: In the presence of CES consumers' preferences and a probability distribution for firms' ex ante productivity, we have shown that the most productive firms invest in the abatement technology and have no emission intensity. Since exporters tend to be more productive and more eco-innovative than non-exporters, we can state the following prediction to be tested in the empirical analysis:

Prediction 1: More productive firms have a higher propensity to invest in a green technology and a higher propensity of exporting than other firms.

Prediction 2: Eco-innovators have a higher export propensity than non-innovators.

Prediction 3: there is a negative direct effect of environmental tax on export propensity for non-innovators and a positive effect on eco-innovation propensity for exporters. The latter effect implies that environmental taxation will indirectly promote export propensity, by stimulating innovation. However, the net effect is ambiguous since the negative direct effect and the positive indirect one will affect differently firm groups.

The direct effect is consistent with the *Pollution Haven Effect*, for which eco-taxes generate higher compliance costs and harm firms' economic performance. By testing the *weak* Porter Hypothesis, we can analyse the positive effect of the environmental tax on the innovation propensity of firms, which is also in line with neoclassical model of environmental policy incentives. By testing the impact of the environmental tax on innovation and, consequently, the effect of innovation on exporting propensity of firms, we can study the indirect effect of a green tax on exports through innovation, which corresponds to the *strong* Porter Hypothesis.

In conclusion, this model can improve our understanding of *Pollution Haven* and *Porter* views by admitting firms' productivity heterogeneity. Firm's heterogeneity may be interpreted as a driver of the relationship among environmental regulation, environmental innovation and exporting propensity. The next Section will describe the econometric methodology to empirically test our predictions using micro-level data.

4. Econometric Model

We aim at empirically evaluating the potential direct and indirect effects of environmental taxation on the exporting probability at firm level, when export participation and eco-innovation upgrading are modelled in terms of dichotomous outcome variables. Our analysis is conducted by implementing the endogenous switching model drawn by Miranda and Rabe-Hescketh (2006). This model accounts for the potential endogeneity of an explanatory variable (eco-innovation) and for the non-linear nature of the relationship between dependent and independent variables[13].

The estimated model is expressed as a system of two latent variables of export and environmental innovation intensity, EXP_j^* and $EnvInno_j^*$. The first equation is

(10) $$EXP_j^* = \beta_1 EnvTax_j + \beta_2 dEnvInno_i + \boldsymbol{\alpha}\, \boldsymbol{X_j'} + u_j$$

(11) $$dEXP_j = \begin{cases} 1 \; if \; EXP_j^* > 0 \\ 0 \; otherwise \end{cases}$$

where $dEXP_j$ is a binary variable that identifies j's firm's export status, $EnvTax_j$ is a dummy variable when there is environmental taxation, $dEnvInno_j$ is a binary variable that concerns environmental innovation and $\boldsymbol{X_j'}$ is a set of control variables. u_j is the error term. β_1, β_2 and $\boldsymbol{\alpha}$ are the parameters to be estimated. The second equation relates to innovation variable and is the following

(12) $$EnvInno_j^* = \delta_1 EnvTax_j + \boldsymbol{\theta}\, \boldsymbol{Z_j'} + \boldsymbol{\gamma}\, \boldsymbol{X_j'} + v_j$$

(13) $$dEnvInno_j = \begin{cases} 1 \; if \; EnvInno_j^* > 0 \\ 0 \; otherwise \end{cases}$$

where $dEnvInno_j$ is a binary variable that identifies if firm j is an eco-innovator, $\boldsymbol{Z_j'}$ is a set of instrumental variables; $\boldsymbol{X_j'}$ **is** the same set of control variables of equation (10); v_j is the error term, δ_1, $\boldsymbol{\theta}$ and $\boldsymbol{\gamma}$ are the parameters to be estimated. Probit models are used for both $dEXP_j$ and $dEnvInno_j$. u_j and v_j are assumed to be bivariate normally distributed. Potential dependence among u_j and v_j has been accounted by using a shared random effect, ε_j. This means that:

[13] For a complete review of binary regression models see Nichols (2011).

(14) $u_j = \lambda\varepsilon_j + \tau_j$

(15) $v_j = \varepsilon_j + \varsigma_j$

where τ_j, ς_j and ε_i are independently normal distributed random variables with 0 mean and variance equal to 1. λ is named *factor loading* and represents a free parameter. The covariance matrix of u_j and v_j is represented as follows:

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

and correlation ρ is given by

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

In this framework, if ρ=0, $dEnvInno_j$ will be exogenous; if ρ≠0, $dEnvInno_j$ is endogenous and correlated with the error term u_j via the unobserved heterogeneity term ε_j. If the potential endogeneity of $dEnvInno_j$ is neglected, biased coefficients of equation (10-11) are obtained. A positive value of λ (so that ρ >0) brings to an upward biased coefficient of the endogenous variable; while a negative value of λ, so ρ<0, implies a downward bias. Furthermore, other covariates' coefficients could differ in sign and size too.

The model uses a Generalized Linear Latent and Mixed Model by stacking the response variables into one variable, q_{jk}. It is supposed that q_{jk} has a binomial distribution. *k* equals 1 if q_{jk} and refers to the main response $dEXP_j$; while *k* equals 2 if it concerns the switching response $EnvInno_j$. Viewing both response variables as clustered within firms, it could be possible to define two dummies, $d_{1kj} = 1$ if *j=1* and d_{2kj} if *k=2*. The conditional mean of q_{jk} is specified as $E(q_{jk}|\varepsilon_j)$ and the link function for responses q_{jk} are probit and could be defined as:

(18) $g_k[E(q_{jk}|\varepsilon_j)] = d_{1kj}(\beta_1 EnvTax_j + \beta_2 dEnvInno_j + \boldsymbol{\alpha}\,\boldsymbol{X}_j' + \lambda\,\varepsilon_j) + d_{2kj}(\delta_1 EnvTax_j + \boldsymbol{\theta}\,\boldsymbol{Z}_j' + \boldsymbol{\gamma}\,\boldsymbol{X}_j' + \varepsilon_j)$

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

The adopted model is quite similar to bivariate probit regression, but they differ in terms of variances. Specifically, in bivariate probit, variances are set equal to 1, while, in the endogenous switching no free parameters are identified for these values[14], so it is possible to convert the latter into the usual bivariate probit through a simple re-parametrization. Since both econometric methodologies show some limits[15], we have also tested our hypothesis with bivariate probit model.

Once coefficients are computed, we consider the marginal effects of the $EnvTax_j$ variable to test the theoretical predictions listed in the previous section. The marginal effect of a change in a variable in the export equation will be the sum of two terms (Greene, 1996; 1998). One will account for the direct effect of a change in that variable on the probability that $dEXP_j$ equals one, and the other will measure the indirect effect of the change in this variable on the probability that $dEnvInno_j$ equals 1 in the eco innovation equation which, in turn, affects the probability that $dEXP_j$ equals one. Thus, for the binary variable, $EnvTax_j$, which appears in $\boldsymbol{X}_j'$, we calculate the direct effect by taking the discrete difference of the probabilities computed with $EnvTax_j$ variable set to the values 1 and 0, as follows:

(19) $E\left[dEXP_j \middle| \boldsymbol{X}_j', \boldsymbol{Z}_j';\ EnvTax_j = 1\right] - E\left[dEXP_j \middle| \boldsymbol{X}_j', \boldsymbol{Z}_j';\ EnvTax_j = 0\right]$

The total effect, which is the sum of direct and indirect effects, is computed by considering the conditional probabilities for eco-innovators with $EnvTax_j$ variable set to the values 1 and 0

(20) $E\left[dEXP_j \middle| \boldsymbol{X}_j', \boldsymbol{Z}_j'; dEnvInno_j = 1 \cap\ EnvTax_j = 1\right] - E\left[dEXP_j \middle| \boldsymbol{X}_j', \boldsymbol{Z}_j'; dEnvInno_j = 1 \cap\ EnvTax_j = 0\right]$

In all cases, standard errors are computed using the delta method.

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[14] Thus, endogenous switching regression generates similar results to bivariate probit but their statistical significance is different.

[15] On one hand, as demonstrated by Nichols (2011), bivariate probit model requires strong parametric assumptions and it is not suitable if endogeneity of other variables is suspected. Additionally, overdispersion of data cannot be properly managed. Furthermore, Miranda and Rabe-Hescketh (2006) have underlined that bivariate probit regression gives approximated and no appropriate distribution results. On the other hand, the endogenous switching model can better deal with higher heteroscedasticity than the bivariate probit.

5. Data Description

In this work, the Eurostat Community Innovation Survey 2008 (CIS2008) and Community Innovation Survey 2014 (CIS2014) have been used to get German manufacturing firms' data. The former dataset reports one observation for each firm with reference to the three-year period 2006-2008; the second one refers to 2012-2014 time-period. Both CIS2008 and CIS2014 are based on Oslo Manual of 2005 and consider all *2-digit level* Nace Rev.2 sectors of the economy. In the present study, we study manufacturing firms export and innovation decisions (see Table 2 for sector description). Net samples include 3060 firms for CIS2008 and 2987 firms for CIS2014. Table 5 and 6 in the Appendix report summary statistics.

5.1 Economic performance and exports

In the literature about the quantitative effects of environmental policies on competitiveness, several measures of trade performance have been used. Some macroeconomic researches largely adopted net trade flows as a measure for competitiveness with reference to aggregate and sectoral data. Tobey (1990), Van Beers and Van Den Berg (2000), Ederington and Minier (2003) and Ederington et al. (2005) have analysed U.S. net imports. In the last two studies net imports have been scaled by shipments in a specific sector at a specific time. Others, such as Mulatu et al. (2003) and Tsurumi et al. (2015), use net exports. Specifically, Mulatu et al. (2003) measure net exports on the total value of production. Few works use imports as international competitiveness measure. For example, Harris et al. (2002) choose the total value of imports while Jug and Mirza (2005) adopt the relative demand for imports in a specific country[16]. Furthermore, Costantini and Mazzanti (2012) consider the volume of trade into a gravity empirical model at industry level. At micro level, Rammer et al. (2017)

[16] With reference to neoclassical studies, other variables are employed to measure competitiveness, such as productivity [Gollop and Roberts (1983), Berman and Bui (2001), Gray and Shadbegian (2003), Becker (2011) and Greenstone (2012)].

contributes to the literature by measuring exporting performance through two variables: exports on total sales at the end of a referring period and a dummy variable for export activities in the last period. In this paper, firm's export status is used ($dEXP_j$) as a measure of economic performance. $dEXP_j$ is equal to 1 if a firm j exports to European Union countries and/or to other extra European Union countries, 0 otherwise. A firm's export status has been interpreted as a measure of economic performance in a microeconomic framework, in view of the existing literature on international trade with heterogeneous firms. International trade propensity is strictly related to the heterogeneous productivity at firm level so that only the most productive firms may serve foreign markets, as we have already stated in Section 3.

5.2 Explanatory Variables

Environmental Regulation

A huge number of studies use binary variables to measure environmental policy[17]. For example, at macro level, Aichele and Felbermayr (2012), by studying the effect of Kyoto Protocol on net emissions embodied in net imports, adopt a binary variable for accounting for this specific regulation[18]. Moreover, Costantini and Mazzanti (2012) account for different types of environmental regulations, such as energy tax, environmental tax, private actions and Environmental Management System implementation. At micro level, Rexhäuser and Rammer (2014) implement a dummy variable that measures if a new innovation is implemented due to a new environmental policy. By following

[17] Concerning environmental regulation and stringency, the most employed measure is the pollution abatement costs expenditure or the pollution abatement operating cost. [Mulatu et al. (2003), Ederington and Minier (2003), Ederington et al. (2005), Brunnermeier and Cohen (2003) and Rubashkina et al. (2015)]. Other studies use energy prices [Sato et al. (2015)] or composite indexes [Albrizio et al. (2017)]. See Brunel and Levinson (2013) for a detailed review.

[18] Greenstone et al. (2012) also account for a specific instrument of the Clean Air Act (pollutant-specific country-level attainment/nonattainment designations), when studying the connection between environmental regulation and productivity.

the same perspective, in this work we use a dichotomous variable ($EnvTax_j$) as a proxy for environmental taxation that captures firm's potential innovation adoption if a pollution tax or charges exists. Specifically, $EnvTax_j$ equals 1 if firms introduce eco-innovation because an environmental tax exists; 0 otherwise[19]. It is necessary to give two specifications. First, for CIS2008 this variable is binary, while for CIS2014 we transform a categorical variable into a dichotomous one[20]. Second, for CIS2014 the adopted variable directly refers to eco-tax or charges, while for CIS2008 it comprehends all types of regulation since we cannot separate taxes from other policies. Since the environmental tax should vary at country or sectoral level but not at firm level, we choose the above-mentioned variables for green tax because we expect that, since firms differ in efficiency, they can perceive tax stringency differently. As theoretically demonstrated in Section 3 firms with a higher productivity have more propensity to implement innovation than the least productive ones and the most productive ones adopt advanced innovation. Thus, the introduction of a tax that fosters firms to adopt advanced abatement technologies is differently perceived by the most efficient firms. These firms probably have a less strict perception of new policies[21].

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[19] CIS2008 survey identifies the existence of an environmental regulation or taxation by asking firms "*During 2006 to 2008, did your enterprise introduce an environmental innovation in response to existing environmental regulations or taxes on pollution?*". For CIS2014, the following question is reported: "*During 2012 to 2014, how important were existing environmental regulation or existing environmental taxes, charges or fees in driving your enterprise's decisions to introduce innovations with environmental benefits?".*

[20] Firms can choose among four degree of importance of the tax in introducing innovation: 0 not important, 1 low importance, 2 medium importance, 3 high importance. For this dataset $EnvTax_j$ is equal to 1 if firms answer 1, 2 or 3, otherwise it is equal to 0.

[21] This is confirmed by our data. Despite the boost of environmental regulation in introducing eco-innovation, the share of firms that do not adopt an eco-innovation decreases if productivity increases. In CIS2008, this share is 6.8% for the least productive firms (productivity lower than the first percentile; it is 5.7% for the most productive ones (productivity higher than the third percentile). CIS2014 corresponding shares are 13.35% and 10.36%, respectively.

As for the effect of environmental regulation, we expect a negative direct effect of environmental tax on exporting propensity due to the existence of compliance costs, in line with the *Pollution Haven Effect* hypothesis. Moreover, in line with the *weak* Porter Hypothesis, which also confirms the theoretical neoclassical position, the effect of eco-tax on innovation is expected to be positive.

Environmental Innovation

The introduction of an environmental innovation should reduce the environmental risk, the amount of emitted pollution and other resources used in the production process. In this study the eco-innovation variable - $dEnvInno_j$ - captures innovation decisions strictly connected to the reduction of the energy use per unit of output and of the total amount of CO_2 produced by the firm. $dEnvInno_j$ is a binary variable which equals 1 if firm j will adopt one or both types of innovation, 0 otherwise[22]. We expect a positive effect on export propensity as predicted by the theoretical model developed in Section 3 and supported by Raxhäuser and Rammer (2014), who adopt a similar measure of environmental innovation[23].

Due to the potential endogeneity of environmental innovation, some instruments are required and come from the CIS2008 and CIS2014 surveys. For our purposes, it is necessary to choose some variables that influence firms' eco-innovation decisions but not their exporting propensity. Chosen instrumental variables are consistent with the already empirically identified drivers of eco-innovation, which are classified into four macro areas by Horbach (2008) and Horbach et al. (2012): demand-pull factors, technology-push factors, environmental regulation, and firms' characteristics. By applying some traditional tests for instrument identification (test for excluded instruments, under-identification

[22] Eco-innovators positively answer to at least one of the following questions: "*During the three years 2006 to 2008[20012 to 2014, CIS2014], did your enterprise introduce a product, process, organisational or marketing innovation with one of these environmental benefits?: 1) reduced energy use per unit of output; 2) reduce CO2 footprint (CO2 total production)?*".

[23] These authors also include other types of environmental technologies, which aim at reducing material use, soil, water and noise pollution, recycling of waste and other materials.

test, weak-instruments robust inference test and the Hansen J over-identification test)[24] on possible instruments, we have identified three instrumental variables. The first one is represented by the cooperation arrangements on innovation activities within the enterprise group ($WithinCO_j$). This measure underlines the importance of knowledge sharing and cooperation for the adoption of innovation [Horbach et al. (2012)], especially in multinational firms. The second instrument, which is the current or expected demand from customers for environmental innovation ($DemandPull_j$), economically reflects an increase in general income level and a substantial customer benefit from eco-friendly products [Kammere (2009)] that consequently increase their environmental awareness. Firms are induced to adopt environmental technologies, that also have an impact on both reputation [Rennings (2000)] and market expansion [Green et al. (1994)]. Finally, the availability of government grants, subsidies or incentives for eco-innovation ($GovIncentives_j$) has been implemented as instrumental variable[25]. As policy push instruments, government incentives represent a crucial driver of eco-innovation, especially in small firms.

By analysing instrumental variables tests, $WithinCO_j$ variable is excluded for CIS2014. This result could refer to a higher presence of intra-group trade which makes $WithinCO_j$.

In this view, we expect a positive and highly significant effect of these instruments on the adoption of environmental innovation [Frondel et al. (2007), Horbach et al. (2012)]. Among the drivers of eco-innovation, specific attention is also devoted to the environmental regulation, which is a control variable for both export and innovation propensity equations. Its effect on the adoption of an abatement technology is fundamental in order to understand the overall effect of a green policy on the exporting propensity of firms.

Other Control Variables

[24] A detailed overview of test results is given in Tables 8.1 and 8.2 in the Appendix.

[25] For CIS2014 these instrumental variables are categorical and measure the degree of importance of demand for green innovations and government incentives.

Some additional control variables account for heterogeneity at firm level. First, size and sector fixed effects are introduced. The empirical literature shows that large firms are more productive than small ones because they take advantage from scale economies. Furthermore, firms' export status is affected by their productivity so that the higher is productivity the higher is export propensity [Melitz and Redding (2014), Bernard and Jensen (1999)]. In this view, a productivity control variable is calculated in terms of firm's relative profitability, as proposed by Aw et al. (2008)[26].

6. Results

6.1 Environmental Innovation: Exogeneity VS. Endogeneity

A preliminary analysis to understand if environmental innovation is an endogenous determinant of export propensity is presented to avoid any potential bias issue. The baseline model (Model 1), whose results are reported in Table 5 of Appendix, is estimated by implementing three kinds of econometric models: exogenous probit model, endogenous switching Maximum Simulated Likelihood (MSL) model and, in line with the previous literature, a bivariate probit model. The former model is based on specification (1) reported in Section 4, while the second and the latter ones refer to equations (1) and (2). As a first result, the hypothesis that the environmental innovation is endogenous cannot be rejected for both CIS2008 and CIS2014 data. As we can see from Column 3 and 6 of Table 5, we find a negative and statistically significant value of rho (at 1% significance level); it is equal to -0.313, for CIS2008, and -0.602, for CIS2014. As it is outlined in Section 4, if we do not account for the potential endogeneity of the innovation variable, biased estimates are obtained. By comparing Probit and MSL coefficients, we can confirm that, if the null hypothesis on rho cannot be rejected, the bias issue exists.

[26] For any firm j, productivity is constructed as follows:

$$Prod_j = \ln\left(\frac{turnover_j}{sector\ turnover}\right) - \frac{1}{n}\sum_j \ln\left(\frac{turnover_j}{sector\ turnover}\right)$$

where n is the number of firms in a specific sector. Turnover is defined as total market sales of goods and services (Including all taxes except VAT).

Specifically, for CIS2008 and CIS2014, the coefficient of $dEnvInno$ is downward biased, thus it is lower (0.099 for CIS2008, and 0.037 for CIS2014) than the value obtained with MSL (0.573 for CIS2008 and 1.010 for CIS2014). This result is also confirmed by bivariate probit estimation. Moreover, by using the exogenous probit model, the coefficient of environmental innovation is not significant, while the MSL and bivariate probit coefficients are highly significant (at 1% significant level).

6.2 The role of environmental taxation

As a second step, we aim at studying the effect of environmental tax on both exporting and adopting eco-innovation propensity of firms. Specifically, we test the direct effect of environmental taxation on exporting propensity (*Pollution Haven Effect*), and the effect of environmental regulation on the probability of being eco-innovative (*weak* Porter Hypothesis).

By comparing the estimated coefficients of eco-tax for both datasets, Column 3 of Table 5 reports a negative but not significant effect of $EnvTax$ on the exporting propensity for CIS2008 (-0.058). Differently, taxation has a significant (at 5% significant level) effect on exporting probability for CIS2014 firms; Column 6 shows a coefficient equal to -0.170. Estimation with the bivariate probit is in line with this result but the coefficient is significant at 10%. From an economic point of view, we can argue that the *Pollution Haven Effect* is confirmed. Firms' competitiveness, measured in terms of trade propensity, is negatively affected by the existence of an environmental tax. By focusing on the impact of the tax on eco-innovation propensity, Table 5 shows that it has a positive and significant (at 1% significance level) effect on the adoption of the abatement innovation for both dataset; Column 3 and 6 corresponding coefficients are equal to 0.526 for CIS2008 and 0.409 for CIS2014. This result supports the *weak* Porter Hypothesis. Moreover, environmental innovation positively increases the probability of exporting. In general, it is possible to assert that this result is in line with Prediction 2, so innovators have a higher probability of exporting than non-innovators.

Concerning control variables, both productivity and size have a significant effect on firms' probability of exporting. Productivity increases the exporting propensity; this means that only the most productive firms decide to export. Focusing on size, different results on small and medium firms confirm the idea that size can be interpreted as an additional measure of efficiency [Bernard and Jensen (1995), Bernard et al. (2007)].

The positive coefficient for productivity partially confirms Prediction 1: more productive firms have a higher propensity to export. Furthermore, productivity has a positive and significant impact on innovating propensity of firms, while size is significant for CIS2008 manufacturing firms only and related coefficients are negative. Some interesting comments on eco-innovation instruments have to be reported. All instruments have a positive and significant effect on the probability of introducing environmental innovation for CIS2008. These results are consistent with the literature on the drivers of environmental innovation [Horbach (2008)] described in Section 5. However, $GovIncentives$ variable has no significant effect for CIS2014.

Environmental taxation by emission intensity

A deeper investigation of the effect of environmental regulation on firms' competitiveness is conducted by accounting for a varying environmental tax coefficient by sector emission intensity. The idea is to capture differences in the stringency of eco policies at sector level. As a preliminary step, we have generated interaction terms that combine $EnvTax$ and the classification of sector by emission intensity. This procedure requires three phases. First, by following Marin et al. (2014), we define three levels of emission intensity - brown, grey and green, which reflect a high, medium and low level of air pollution emissions. Second, three dummies have been generated ($Green$, $Grey$ and $Brown$) and each one is equals 1 if a sector shows an emission intensity level that corresponds to one of the above categories, 0 otherwise. Finally, three interaction variables are obtained by multiplying emission intensity dummies by environmental tax covariate, and used in Model 2.

The analysis implements both bivariate probit and the endogenous switching models, as in the previous section. Estimates are reported in Table 6 of the Appendix.

A first result shows that $EnvTax$ variable has a statistically significant (at 1%, for CIS2008, and 10%, for CIS2014) and negative effect for exporting propensity of brown sector firms. This result confirms the *Pollution Haven Effect*, but it seems to lose significance in 2012-2014 period. Bivariate probit estimated on $EnvTaxBrown$ of CIS2014 are in line with endogenous switching estimates but it is not statistically significant. For green and grey sector firms, a tax does not have a significant impact on their export status. On the contrary, if we analyse the effect of the eco-tax on the probability of introducing an abatement technology, a general positive and significant value is registered for both datasets, whatever is the considered sector. We can affirm that the *weak* Porter Hypothesis is also confirmed if environmental tax coefficient is differentiated by emission intensity.

Concerning the other explanatory variables, the adoption of eco-innovation has always a positive and significant impact on firms' export status, so eco-innovators have a higher propensity to be also exporters. Finally, results on productivity and size are confirmed and instrumental variables, except the existence of government incentives, play a relevant role for the adoption of green technologies as before.

In the following step, we have analysed direct and total effects of environmental tax on exporting propensity. Focusing on CIS2008 firms, there is a strong negative direct effect of the environmental tax on exporting propensity for green and brown sector firms, when the endogenous switching model is implemented. This is in line with the *Pollution Haven Effect* theory, but, as it is shown by Column 1 of Table 7, the total effect is negative too but not statistically significant. This result is also confirmed when bivariate probit is used but for brown sector firms only. Concerning grey sector firms, Table 8 shows that the eco-tax generates a positive and significant direct effect on firm exporting probability; a 4.8% increase is registered. Additionally, if firms adopt an eco-innovation, the impact of environmental policy on export status is enhanced; the statistically significant total effect is equal to 6%. If marginal effects are estimated through the bivariate probit, the environmental tax operates through innovation only.

Focusing on CIS2014 data, no significant results are obtained by estimating direct and total effect through bivariate probit; differently, if endogenous switching model is chosen, the eco-tax affects the exporting propensity of firms, whatever are their decision about innovation. For green sector firms, it entails a 1% increase, while, for brown sector firms the *Pollution Haven Effect* is confirmed. The introduction of a green regulation brings to an increase of compliance costs, which consequently reduces the exporting probability of 6.4%. Furthermore, if grey sector firms are considered, the eco-tax affects the probability of being an exporter only if they adopt eco-innovation. The corresponding conditional probability is -2.5%, so being an eco-innovator decreases the probability of exporting if an environmental regulation is imposed. Finally, no evidence of the *strong Porter Hypothesis* is generally obtained.

In order to support our hypothesis about the importance of productivity heterogeneity across firms in explaining the relationship among eco regulation, eco innovation and exporting propensity, we compute direct and total effects at three different levels of productivity (25° percentile, median, 75° percentile) with reference to the endogenous switching estimates. Results are graphically described and reported in Figure 1 of Appendix A. By analysing both effects, we have found some similarities among CIS2008 and CIS2014 datasets. First, depending on the productivity level, they behave similarly, but the total effect is less statistically significant than the direct one; indeed, as Figure 1 shows, the correspondent curve partially or totally lies inside the confidence interval[27]. Second, for more productive firms, the entity of the total and direct effects is almost equal, so the environmental policy especially affects exporting performance directly. Conversely, the total effect is stronger than direct one for less productive firms; the highest value refers to 25° percentile. Third, if we study brown sector firms, both effects are negative, but the higher the productivity, the lower is the absolute value of each effect.

[27] The confidence interval is fixed at 90%.

Concerning green and grey sector firms, CIS2008 and CIS2014 firms show opposite results. Specifically, direct and total effects have a negative value, when green sector firms of CIS2008 are considered; for grey sector firms, positive effects are registered. In both situations, the effect decreases if the productivity level grows. Opposite results are obtained when CIS2014 data are studied.

7. Robustness analysis by firm size

In this section, we deeply study the effect of existing environmental taxes on three firms' subsamples: small, medium and large firms. This type of analysis is useful because we expect that firms could react differently to regulation depending on their size. The analysis is based on the same model specifications used in previous sections, by implementing both endogenous switching and bivariate probit estimations. Results are reported in Table 8.1, 8.2 and 8.3.

Starting from small firm sample and concerning both CIS2008 and CIS2014 data, Table 8.1 shows that the environmental tax does not have a significant effect on exporting propensity of firms. Specifically, when we account for environmental tax, it has a positive effect on the exports status, except for brown sector firms when Model 2 is estimated, but it is not statistically significant. Unfortunately, also the adoption of environmental innovation does not significantly affect the exporting propensity of manufacturing firms, so Prediction 2 of the theoretical model is not verified. Some remarks on the estimates of the relationship between taxation and innovation are necessary. The environmental taxation has a positive and significant influence on eco-innovation adoption for CIS2008 small firms, whichever is the referring sector and the estimated model specification. This is also verified for CIS2014 firms but, grey sector coefficient is not statistically significant. As we can see from Column 1-2 and 5-6 of Table 8.1, coefficients are positive and significant (1% or 10%). Results are also verified if a bivariate probit estimator is implemented. Furthermore, green innovation is substantially driven by demand pull factor, thus the demand for abatement innovation from customers increases the probability of adopting eco-innovation; coefficients are positive and significant (at 1% level of significance). Among other instrumental variables, Column 1 and 5 show that the existence of government incentives has a positive and significant impact (at 10%) on eco-innovation introduction, if we estimate Model 1, through the endogenous switching model, for CIS2008 and Model 2 for CIS2014. For CIS2008, results lose robustness by applying bivariate probit. Finally, collaboration among firms of the same group fosters innovation when tax coefficient is differentiated by emission intensity for CIS2008 firms and the endogenous switching is applied.

Interesting results refer to productivity. It seems to be the only driver of exporting propensity for this type of firms; its coefficient is the only statistically significant one (1%). This is verified for all specification and estimators. Concerning its effect on the implementation of eco-innovation, it positively and significantly affects this behaviour exclusively in CIS2014 small firms.

As reported by Table 8.2, different results are obtained for medium firms. First, focusing on the existence of an eco-tax, data show that it generally decreases the probability of exporting when Model 1 is estimated with endogenous switching for CIS2014 and bivariate probit for CIS2008. Corresponding coefficients are statistically significant at 10% and 5%. Proceeding with the analysis, when $EnvTax$ coefficient is differentiated by emission intensity, so Model 2 is estimated, environmental tax has a negative effect for brown sector firms, and green sector when bivariate probit is implemented and CIS2008 are considered. Brown sectors coefficient is equal to -0.419 with endogenous switching and to -0.552 with bivariate probit; while, it is equal to -0.825 for green sectors. Concerning $EnvTaxGreen$, the second estimation gives a higher level of significance, 1%, than the former, 10%. Focusing on CIS2014 medium firms, the negative and significant effect of environmental taxation on export status is connected to grey sector firms. Column 6 and 8 of Table 8.2 reports negative coefficients for $EnvTaxGrey$ and they are equal to -0.468 and -0.804. In general, we can assert that the *Pollution Haven Effect* is confirmed for medium firms, especially for brown and grey sector ones. Second, by analysing the effect of the tax in introducing eco-innovation, the positive and significant effect of the environmental taxation on eco-innovation implementation is confirmed and is related to all sectors firms. However, for CIS2014 it is driven by grey sector firms only.

Third, differently from small firms, theoretical Prediction 2 is verified, thus being an environmental innovator increases the probability of exporting; all coefficients are positive and significant except when CIS2014 firms are considered and bivariate probit is implemented.

Finally, results on productivity and $DemandPull$ variables have been confirmed. Government incentives are statistically significant for CIS2008 firms but not for CIS2014 ones. Collaboration within the same firm group does not drive the introduction of innovation at all.

By examining Table 8.3, we can see that, for large firms, taxation has no significant effect on firms' probability of being an exporter, except for CIS2008 green sector firms; Column 4 reports a positive and statistically significant coefficient equal to 5.207[28]. Being a large and green firm means being more efficient and competitive on markets, so the introduction of an eco-tax fosters firms to be even more competitive through exports. Estimates that concern the propensity of introducing an eco-innovation confirm the positive and significant role of taxation. It seems that this result is driven by grey sector firms for CIS2008, coefficients are equal to 0.377, with endogenous switching model, and 0.379, with bivariate probit estimation, and by green sector firms for CIS2014, the corresponding coefficient is equal to 0.527. An interesting result is related to productivity. It is a relevant driver for the adoption of innovation but not for exporting when CIS2008 dataset is considered and endogenous switching model is applied. This result is in line with the literature, which suggests that more productive firms are also the larger ones, so an additional increase of productivity marginally affects the exporting propensity. Results on eco-innovation driver are confirmed for large firms as well.

8. Conclusions

In a scenario where trade and innovation play a relevant role for sustainable development and environmental policies are constantly improved in order to preserve natural resources and to account

[28] Since large firms' samples are smaller than others, results have to be carefully analyzed.

for climate change, many researchers have studied the links between environmental policy, environmental innovation and trade performance. The existing empirical evidence has underlined a strong relation among all these aspects, especially at macro level. This paper has contributed to the literature by considering the role of firms' productivity heterogeneity on environmental policies, innovation and trade dynamics. Specifically, results confirm that heterogeneity across firms - in terms of productivity, of adopted technology and size - is important in defining the relationship between green policies, green technologies and trade decisions.

Our econometric analysis has provided different insights. First, the hypothesis of the Pollution Haven Effect is generally confirmed for German firms with reference to CIS2014 only, in line with Prediction 2. Furthermore, the *weak* Porter hypothesis, which is also confirmed by previous researches, is also confirmed and eco innovation positively affects the probability of exporting. Second, when the coefficient of regulation is distinguished by emission intensity at sector level, it has a negative effect only on exporting propensity of brown sector firms, but this result loses some robustness over time from CIS2008 to CIS2014. Generally, we can assert that, being exporters also means being eco-innovator.

By testing the direct and total effects of environmental tax on exporting propensity of firms, we find robust evidence for the *Pollution Haven Effect* but not for the *strong Porter Hypothesis*. Furthermore, through an analysis by productivity level, we have demonstrated that, on one side, the higher is the productivity, the lower is the difference among the two effects, so the total effect especially affects less productive firms; on the other side, direct and indirect effects are positive when grey sector firms of CIS2008 and green sector firms of CIS2014 are considered. By combining these results, we can assert that grey or green sector firms could have a higher propensity of being exporters if eco-innovation is introduced due to the existence of environmental regulation and their productivity is low.

Finally, we have also conducted a robustness analysis of data by testing the relationship among trade, policy and innovation on three subsamples of firms, which refer to their size. For small firms, results do not substantially change over time by comparing CIS2008 and CIS2014. Environmental taxation does not represent an important driver of the exporting propensity of small firms, while it has a significant impact on innovating propensity, especially for green and brown sectors firms. Exporting probability of small firms seems to be only driven by productivity. For this subsample, environmental innovation seems to have no impact on trade decision of firms. Moreover, the existence of a demand of eco-innovations is fundamental for the adoption of eco-innovation. Results on medium firms show that a green tax has a negative effect on the probability of exporting for brown firms of CIS2008. As regard to CIS2014 firms, this is also confirmed for grey sector firms. For medium firms, the adoption of eco-innovation is a significant driver for being an exporter. Finally, results on large firms underline that environmental tax has a positive impact on exporting propensity of CIS2008 green firms. Furthermore, in line with the literature, it positively affects the environmental innovation adoption but for grey sector firms only. Concerning other variables, we can generally assert that productivity significantly increases firms' probability to export, except for large firms, and to innovate, so the most productive firms export and adopt environmental innovation. This is in line with our theoretical Prediction 1. Moreover, eco-innovation seems to be driven especially by demand for eco-friendly technologies by consumers, and by government incentives too when large firms are analysed.

From a policy point of view, our results suggest that authorities should implement tax, fees or charges by carefully considering firms' heterogeneity, in terms of productivity levels and especially by emission intensity at sector level and size. Furthermore, public efforts in lowering pollution should be concentrated to more polluting sectors and supported by a system of incentives.

Further research could be done by distinguishing among different types of eco-innovations, such as end-of-pipe and cleaner-production technologies. This kind of analysis could be useful because they require different levels of fixed and variable costs, and their effect on exporting propensity may vary. Another improvement channel for this work is represented by a cross-country comparison of European Union firms. It would be fundamental to give some insights about the adoption of common environmental regulations, which can be adopted at different time and with different methods by countries. Moreover, in each country, firms could introduce, or not, eco-innovation and the drivers could be different.

References

Aichele, R. and Felbermayer, G. (2012), "Kyoto and the carbon footprint of nations", *Journal of Environmental Economics and Management*, Vol. 63, N. 3, pp. 336-354

Albrizio, S., Kozluk, T. and Zipperer, V. (2017), "Environmental policies and productivity growth: evidence across industries and firms", *Journal of Environmental Economics and Management*, Vol. 81, pp. 209-226

Ambec, S. and Barla, P. (2002), "A theoretical foundation of the Porter Hypothesis", *Economics Letters*, Vol. 75, pp. 255-360

Ambec, S., Cohen, M. A., Elgie, S. and Lanoie, P. (2013), "The Porter Hypothesis at 20: Can environmental regulation enhance innovation and competitiveness?", *Review of Environmental Economics and Policy*, Vol.7, Issue 1, pp.2-22

Aw, B.Y., Roberts, M. J. and Yi Xu, D. (2008), "R&D Investments, Exporting and the Evolution of Firm Productivity", *American Economic Review*, Vol. 98, N. 2, pp. 451-456.

Becker, R. A. (2011), "Local environmental regulation and plant-level productivity", *Ecological Economics*, Vol. 70, pp. 2516-2522

Berman, E. and Bui, L. T. M. (2001), "Environmental regulation and productivity: evidence from oil refineries", *The Review of Economics and Statistics*, Vol. 83, N. 3, pp. 498-510

Bernard, A. B. and Jensen, J. B. (1995), "Exporters, Jobs and Wages in U.S. Manufacturing: 1976-1987", *Brookings Paper: Microeconomics*, Vol. 26, pp. 67-119

Bernard, A. B. and Jensen, J. B. (1999), "Exporting and productivity", *NBER Working paper,* N. 7135

Bernard, A. B., Eaton, J., Jensen, J. B. and Kortum, S. (2007), "Plants and Productivity in international trade", *American Economic Review*, Vol. 93, N. 4, pp. 1268-1290

Brunel, C. and Levinson, A. (2013), “Measuring environmental regulatory stringency”, *OECD Trade and Environment Working Paper*, N. 5

Brunnermeier, S. B. and Cohen, M. A. (2003), “Determinants of environmental innovation in US manufacturing industries”, *Journal of Environmental Economics and Management*, Vol. 45, pp. 278-293

Broberg, T., Marklund, P. O., Samakovlis, E. and Hammar, H. (2013), “Testing the Porter Hypothesis: the effects of environmental investments on efficiency in Swedish industries”, *Journal of Productivity Analysis*, vol. 40, pp. 40-56

Bustos, P. (2011), "Trade Liberalization, Exports, and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms", *American Economic Review, Vol.* 101, N. 1, pp. 304-40

Cao J., Qiu L. D., Zhou M. (2016), “Who invest more in advanced abatement technology? Theory and evidence”, *Canadian Journal of Economics*, Vol. 49, pp. 637 -662

Cherniwchan, J., Copeland, B. R. and Taylor, M. S. (2017), “Trade and environment: new methods, measurements, and results”, *Annual Review of Economics*, Vol. 9, N.1, pp. 59-85

Cohen, M. A. and Tubb, A. (2017), “The impact of environmental regulation on firm and country competitiveness: a meta–analysis of the Porter Hypothesis”, *Vanderbilt Owen Graduate School of Management Research Paper*, N. 2692919

Copeland, B. R. and Taylor, M. S. (1994), “North-South trade and the environment”, *The Quarterly Journal of Economics*, Vol. 109, N. 3, pp. 755–787

Copeland, B. R. and Taylor, M. S. (2004), “Trade, growth, and the environment”, *Journal of Economic Literature*, Vol. XLII, pp. 7-71

Costantini, V. and Mazzanti, M. (2012), “On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports”, *Research Policy*, pp. 132-153

Cui, J., Lapan, H. and Moschini, G. (2017), "Induced Clean Technology Adoption and International Trade with Heterogeneous Firms" *Journal of International Trade & Economic Development*, Vol. 26, N. 8, pp. 924-954

Dechezleprêtre, A. and Sato, M. (2017), “The impacts of environmental regulations on competitiveness”, *Review of Environmental Economics and Policy*, Vol. 11, N. 2, pp. 183-206

Ederington, J. and Minier, J. (2003), “Is environmental policy a secondary trade barrier? An empirical analysis”, *Canadian Journal of Economics*, Vol. 36, N. 1, pp. 137-154

Ederington, J., Levinson, A. and Minier, J. (2005), “Footloose and pollution-free”, *The Review of Economics and Statistics*, Vol. 85, N. 1, pp. 92-99

Forslid, R., Okubo, T. and Ulltveit-Moe, K.H. (2018), “Why are firms that export cleaner? International trade, abatement and environmental emissions”, *Journal of Environmental Economics and Management,* Vol. 91, pp. 166-183

Franco, C. and Marin, G. (2017), “The Effect of Within-Sector, Upstream and Downstream Environmental Taxes on Innovation and Productivity”, *Environmental and Resource Economics,* Vol. 66, Issue 2, pp. 261-291

Frondel, M., Horbach, J. and Rennings, K. (2007), “End-of-Pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries”, *Business Strategy and the Environment*, Vol. 16, pp. 571-584

Gray, W. B. and Shadbegian, R. J. (2003), “Plant vintage, technology, and environmental regulation”, *Journal of Environmental Economics and Management*, Vol. 46, pp. 384-402

Green, K., McMeekin, A. and Irwin, A. (1994), "Technological trajectories and R&D for environmental innovation in UK firms", *Futures*, Vol. 26, N. 10, pp. 1047-1059

Greene, W.H. (1996), "Marginal Effects in the Bivariate Probit Model", NYU Working Paper No. EC-96-11.

Greene, W.H. (1998), "Gender Economics Courses in Liberal Arts Colleges: Further Results", *The Journal of Economic Education*, Vol. 29, N. 4, pp 291-300

Greenstone, M., List, J. A. and Syverson, C. (2012), "The effects of environmental regulation on the competitiveness of U. S. manufacturing", *NBER Working Paper Series*, N. 18392

Gollop, F. M. and Roberts, M. J. (1983), "Environmental regulations and productivity growth: the case of fossil-fueled electric power generation", *Journal of Political Economy*, vol. 91, N. 4

Grossman G.M. and Helpman E. (1991), "Innovation and growth in the global economy", *Cambridge MIT Press*

Grossman, G. M. and Krueger, A. B. (1991), "Environmental impact of a North American Free Trade Agreement", *NBER Working Paper Series*, N. 3914

Harris M., N., Kónya L. and Mátyás L. (2002), "Modelling the impact of environmental regulations on bilateral trade flows: OECD, 1990-1996", *The World Economy*, Vol. 25, N. 3, pp. 387-405

Holladay, J., S. (2016), "Exporters and the environment", *Canadian Journal of Economics*, Vol. 49, N. 1, pp. 147-172

Horbach, J. (2008), "Determinants of environmental innovation-new evidence from German panel data", *Research Policy*, Vol. 37, pp. 163-173

Horbach, J., Rammer, C. and Rennings, K. (2012), "Determinants of eco-innovation by type of environmental impact – The role of regulatory push/pull, technology push and market pull", *Ecological Economics*, vol. 78, pp. 112-122

Jaffe, A. B., Peterson, S. R. and Portney, P. R. (1995), “Environmental regulation and the competitiveness of U. S. manufacturing; what does the evidence tells us?”, *Journal of Economic Literature*, Vol. 33, pp. 132-163

Jaffe, A. B. and Palmer, K. (1997), “Environmental regulation and innovation: a panel data study”, *Review of Economics and Statistics*, Vol. 29, N. 4, pp. 610-619

Jug, J. and Mirza, D. (2005), “Environmental regulations in gravity equations: evidence from Europe”, *The World Economy*, Vol. 28, Issue 11, pp. 1591-1615

Jung, C., Krutilla, K. and Boyd, R. (1996), “Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives”, *Journal of Environmental Economics and Management*, Vol. 30, N. 1, pp. 95-111

Kammere, D. (2009), “The effect of customer benefit and regulation on environmental product innovation. Empirical evidence from appliance manufacturers in Germany”, *Ecological Economics*, Vol. 68, pp. 2285-2295

Kreickermeier U., Richter P. M. (2014), “Trade and the environment: the role of firm heterogeneity”, *Review of International Economics*, Vol. 22, pp. 209-225

Lanoie, P., Patry, M. and Lajeunesse, R. (2008), “Environmental regulation and productivity: testing the Porter Hypothesis”, *Journal of Productivity Analysis*, vol. 30, pp. 121-128

Lanoie, P., Laurent-Lucchetti, J., Johnstone, N., Ambec, S. (2011), “Environmental policy, innovation and performance: new insights on the Porter Hypothesis”, *Journal of Economics & Management Strategy*, Vol. 20, N. 3, pp. 803-842

Marin G., Marzucchi, A., Zoboli, R. (2014), “SMEs and Barriers to Eco-Innovation in EU: A Diverse Palette of Greens”, *SEEDS Working Paper 0614*, Sustainability Environmental Economics and Dynamics Studies

Melitz, M. (2003), “The impact of trade on intra-industry reallocations and aggregate industry productivity”, E*conometrica*, Vol. 71, N. 6, pp. 1695-1725

Melitz, M. J. and Redding, S. J. (2014). “Heterogenous firms and trade”, *Handbook of International Economics*, 4th ed., pp. 1-54, Elsevier

Milliman, S. R. and Prince, R. (1989), “Firms incentives to promote technological change in pollution control”, *Journal of Environmental Economics and Management*, Vol. 44, pp. 23-44

Miranda, A. and Rabe-Hesketh, S., (2006), “Maximum likelihood estimation of endogenous switching and sample selection models for binary, ordinal, and count variables”, *The Stata Journal*, Vol. 6, Number 3, pp. 285-308

Mulatu, A., Florax, R. J. G. M. and Withagen, C. A. (2003), “Environmental regulation and international trade: empirical results for the manufacturing industry in Germany, the Netherlands and the US, 1972-1992”, *The BE Journal of Economic Analysis & Policy*, Vol. 15, N. 4, pp. 1549-1577

Nichols, A. (2011), “Causal inference for binary regression”, Stata Conference, July, 14 2011

Piccardo, C., Bottasso, A. and Benfratello, L. (2014), " Innovative capacity and export performance: Exploring heterogeneity along the export intensity distribution", Centre for Studies in Economics and Finance (CSEF) Working Papers 371

Porter, E. M. and Van Der Linde, C. (1995), “Toward a new conception of the environment-competitiveness relationship”, *Journal of Economic Perspective*, Vol. 3, N. 2, pp. 1-30

Porter, E. M. (1991), “America’s green strategy”, *Essay on Scientific American*

Rammer, C., Gottschalk, S., Peneder, M., Wörter, M., Stucki, T. and Arvanitis, S. (2017), “Does energy hurt international competitiveness of firms? A comparative study for Germany, Switzerland and Austria”, *Energy Policy*, Vol. 109, pp. 154-180

Raxhäuser, S. and Rammer, C. (2014), “Environmental innovations and firm profitability: unmasking the Porter Hypothesis”, *Environmental and Resources Economics*, Vol. 57, pp. 145-167

Rennings, K. (2000), “Redefining innovations-eco innovation research and the contribution from ecological economics”, *Ecological Economics*, Vol. 32, pp. 319-342

Requate, T. (2005), “Dynamic incentives by environmental policy instruments – a survey”, *Ecological Economics*, Vol. 54, N. 2-3, pp. 175-195

Rubashkina, Y., Galeotti, M. and Verdolini, E. (2015), “Environmental regulation and competitiveness: empirical evidence on the Porter hypothesis from European manufacturing sectors”, *Energy Policy*, pp. 288-300

Sato, M., Singer, G., Dussaux, D. and Lovo, S. (2015), “International and sectoral variation in energy prices 1995-2011: how does it relate to emissions policy stringency?”, *Centre for Climate Change Economics and Policy Working Paper*, N. 212

Tavassoli S. (2013), “The Role of Production Innovation Output on Export Behaviour of Firms”, *CSIR Electronic Working Paper Series*, N. 2013/5

Taylor, M. S. (2005), "Unbundling the Pollution Haven Hypothesis", *The B.E. Journal of Economic Analysis & Policy*, Vol. 4, Issue 2

Tobey, J. A. (1990), “The effects of domestic environmental policies on patterns of world trade: an empirical test”, *Kyklos*, Vol. 43, N. 2, pp. 191-209

Tsurumi, T., Managi, S. and Hibiki, A. (2015), “Do environmental regulations increase bilateral trade flows?”, *The BE Journal of Economic Analysis & Policy*, Vol. 15, N. 4, pp. 1549-1577

Van Beers, C. and Van Den Bergh, J. C. J. M. (2000), “The impact of environmental policy on foreign trade”, *Tinbergen Institute Discussion Paper*, N. 69, 15 pp.

Van Leeuwen, G. and Mohnen, P. (2017), “Revisiting the Porter Hypothesis: an empirical analysis of green innovation for the Netherlands”, *Economics of Innovation and New Technology*, Vol. 26, pp. 63-77

Yeaple, S. R. (2005), "A simple model of firm heterogeneity, international trade, and wages*”*, *Journal of International Economics*, Vol. 65, N. 1, pp. 1-20

Appendix A - Tables

Table 1.1 Variables Description – CIS2008

Variable	Description
dEXP	Dummy variable that refers to exporting propensity of firms: equal to 1 if firm exports, 0 otherwise
EnvTax	Dummy related to environmental regulation: equal to 1 if firm introduces an eco-innovation due to present environmental regulation or tax, 0 otherwise
dEnvInno	Dummy related to the introduction of eco-innovation: equal to 1 if firm introduces an eco-innovation that reduces the amount of CO2 produced and/or the energy use, 0 otherwise
WithinCO	Dummy equals to 1 if a firm has cooperation arrangements on innovation activities within the enterprise group, 0 otherwise
DemandPull	Dummy equals to 1 if a firm introduces eco-innovation because of the current or expected demand from customers for environmental innovation, 0 otherwise
GovIncentives	Dummy equals to 1 if a firm introduces eco-innovation because of the availability of government grants, subsidies or other financial incentives, 0 otherwise
Prod	Firms' s relative profitability, Aw et al. (2010)
dsmall	Dummy equals to 1 if a firm has <50 employees, 0 otherwise
dmedium	Dummy equals to 1 if a firm has a number of employees between 50 and 250, 0 otherwise
dlarge	Dummy equals to 1 if a firm has >250 employees, 0 otherwise
ds1-ds7	Seven dummies referring to sectors at *2-digit* level Nace Rev. 2 classification
Green	Dummy equals to 1 if a firm operates in a green or low emission intensity sector, 0 otherwise
Grey	Dummy equals to 1 if a firm operates in a grey or medium emission intensity sector, 0 otherwise
Brown	Dummy equals to 1 if a firm operates in a brown or high emission intensity sector, 0 otherwise

Table 1.2. Variables Description – CIS2014

Variable	Description
dEXP	Dummy variable that refers to exporting propensity of firms: equal to 1 if firm exports, 0 otherwise
EnvTax	Dummy variable equals to 1 if the degree of importance of existing environmental taxes or charges is equal to 1 (low), 2 (medium) or 3 (high), 0 otherwise
dEnvInno	Dummy related to the introduction of eco-innovation: equal to 1 if firm introduces an eco-innovation that reduces the amount of CO2 produced and/or the energy use, 0 otherwise
DemandPull	Dummy equals to 1 if firm introduces eco-innovation because of the current or expected demand from customers for environmental innovation, 0 otherwise
GovIncentives	Dummy equals to 1 if firm introduces eco-innovation because of the availability of government grants, subsidies or other financial incentives, 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
Green	Dummy equals to 1 if a firm operates in a green or low emission intensity sector, 0 otherwise
Grey	Dummy equals to 1 if a firm operates in a grey or medium emission intensity sector, 0 otherwise
Brown	Dummy equals to 1 if a firm operates in a brown or high emission intensity sector, 0 otherwise

Table 2.1. Manufacturing sector description – CIS2008

Nace Rev. 2	**Description**	**Emission intensity**
C10_C12	Manufacture of goods and products, beverage and tobacco products	Brown
C13_C15	Manufacture of textile, wearing apparel, leather and related products	Grey
C16_C18	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; printing and reproduction of recorded media	Brown
C19_C23	Manufacture of coke and refined petroleum products, chemicals and chemical products, basic pharmaceutical products and pharmaceutical preparations, rubber and plastic, other non-metallic mineral products	Brown
C24_C25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	Brown
C26_C30	Manufacture of computer, electronic and optical products, electrical equipment, machinery and equipment n.e.c., motor vehicles, trailers and semi-trailers, other transport equipment	Grey
C31_C33	Manufacture of furniture, repair and installation of machinery and equipment, other manufacturing	Green

Table 2.2. Manufacturing sectors description – CIS2014

Nace Rev. 2	Description	Emission Intensity
C10_C12	Manufacture of goods, products, beverage, tobacco products	Grey
C13	Manufacture of textile	Grey
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	Brown
C17	Manufacture of paper and paper products	Brown
C18	Printing and reproduction of recorded media	Grey
C19_C20	Manufacture of coke and refined petroleum products, chemicals and chemical products	Brown
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	Grey
C22	Manufacture of rubber and plastic products	Brown
C23	Manufacture of other non-metallic mineral products	Brown
C24	Manufacture of basic metals	Grey
C25	Manufacture of fabricated metal products, except machinery and equipment	Green
C26	Manufacture of computer, electronic and optical products	Green
C27	Manufacture of electrical equipment	Green
C28	Manufacture of machinery and equipment n.e.c.	Green
C29	Manufacture of motor vehicles, trailers and semi-trailers	Grey
C30	Manufacture of other transport equipment	Green
C31	Manufacture of furniture	Green
C32	Other manufacturing	
C33	Repair and installation of machinery and equipment	Green

Table 3.1.. Summary Statistics – CIS2008

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
dEXP	3,060	0.724	0.447	0	1
dEnvInno	2,709	0.538	0.499	0	1
EnvTax	2,662	0.304	0.460	0	1
EnvRegGreen	2,662	0.148	0.355	0	1
EnvRegGrey	2,662	0.046	0.210	0	1
EnvRegBrown	2,662	0.110	0.314	0	1
Prod	3,060	-0.153	2.117	-5.555	7.368
dsmall	3,060	0.396	0.489	0	1
dmedium	3,060	0.364	0.481	0	1
dlarge	3,060	0.240	0.427	0	1
ds1	3,060	0.094	0.292	0	1
ds2	3,060	0.048	0.213	0	1
ds3	3,060	0.097	0.296	0	1
ds4	3,060	0.180	0.384	0	1
ds5	3,060	0.132	0.339	0	1
ds6	3,060	0.345	0.475	0	1
ds7	3,060	0.104	0.305	0	1
DemandPull	2,662	0.227	0.419	0	1
GovIncentives	2,662	0.059	0.236	0	1
WithinCO	2,773	0.115	0.319	0	1
Green	3,060	0.104	0.305	0	1
Grey	3,060	0.487	0.500	0	1
Brown	3,060	0.409	0.492	0	1

Table 3.2. Summary statistics – CIS2014

Variable	Obs	Mean	Std. Dev.	Min	Max
dEXP	2,987	0.729	0.444	0	1
dENVINNO	2,485	0.563	0.496	0	1
EnvTax	2,252	0.355	0.478	0	1
EnvTaxGreen	2,252	0.146	0.354	0	1
EnvTaxGrey	2,252	0.086	0.281	0	1
EnvTaxBrown	2,252	0.087	0.283	0	1
DemandPull	2,249	0.387	0.487	0	1
GovIncentives	2,250	0.307	0.461	0	1
Prod	2,986	-0.100	2.067	-6.394	6.494
ds1	2,987	0.092	0.289	0	1
ds2	2,987	0.030	0.172	0	1
ds3	2,987	0.027	0.162	0	1
ds4	2,987	0.028	0.166	0	1
ds5	2,987	0.025	0.157	0	1
ds6	2,987	0.029	0.169	0	1
ds7	2,987	0.057	0.232	0	1
ds8	2,987	0.021	0.143	0	1
ds9	2,987	0.053	0.225	0	1
ds10	2,987	0.041	0.198	0	1
ds11	2,987	0.033	0.179	0	1
ds12	2,987	0.112	0.315	0	1
ds13	2,987	0.101	0.301	0	1
ds14	2,987	0.053	0.225	0	1
ds15	2,987	0.120	0.325	0	1
ds16	2,987	0.039	0.195	0	1
ds17	2,987	0.019	0.136	0	1
ds18	2,987	0.024	0.155	0	1
ds19	2,987	0.038	0.192	0	1
ds20	2,987	0.049	0.217	0	1
Green	2,987	0.431	0.495	0	1
Grey	2,987	0.208	0.406	0	1
Brown	2,987	0.242	0.428	0	1

Table 4.1. Correlation matrix – CIS2008

	dEXP	*EnvTax*	*EnvTaxGreen*	*EnvTaxGrey*	*EnvTaxBrown*	*dEnvInno*	*Prod*	*WithinCO*	*DemandPull*	*GovIncentives*
dEXP	1									
EnvTax	0.106	1								
EnvTaxGreen	0.121	0.557	1							
EnvTaxGrey	0.036	0.291	-0.070	1						
EnvTaxBrown	-0.019	0.460	-0.111	-0.058	1					
dEnvInno	0.104	0.318	0.132	0.114	0.179	1				
Prod	0.345	0.234	0.141	0.069	0.109	0.244	1			
WithinCO	0.155	0.179	0.152	0.009	0.061	0.178	0.386	1		
DemandPull	0.144	0.340	0.233	0.091	0.123	0.300	0.225	0.251	1	
GovIncentives	0.030	0.218	0.086	0.121	0.131	0.154	0.092	0.129	0.251	1

Table 4.2. Correlation matrix – CIS2014

	dEXP	*EnvTax*	*EnvTaxGreen*	*EnvTaxGrey*	*EnvTaxBrown*	*dEnvInno*	*Prod*	*DemandPull*	*GovIncentives*
dEXP	1								
EnvTax	0.102	1							
EnvTaxGreen	0.123	0.517	1						
EnvTaxGrey	0.027	0.440	-0.132	1					
EnvTaxBrown	-0.045	0.440	-0.132	-0.112	1				
dEnvInno	0.112	0.306	0.137	0.124	0.167	1			
Prod	0.285	0.218	0.108	0.110	0.109	0.248	1		
DemandPull	0.144	0.519	0.302	0.203	0.217	0.313	0.215	1	
GovIncentives	0.060	0.589	0.316	0.256	0.267	0.260	0.121	0.556	1

Table 5. Bivariate Probit and Maximum Simulated Likelihood Estimation, Model 1

	CIS2008			CIS2014		
	Probit	**Bivariate Probit**	**ESM**	**Probit**	**Bivariate Probit**	**ESM**
	b/se					
dEXP						
dENVINNO	0.099	0.735***	0.573***	0.037	1.025***	1.010***
	(0.061)	(0.176)	(0.206)	(0.069)	(0.260)	(0.132)
EnvTax	0.066	-0.121	-0.058	0.069	-0.187*	-0.170**
	(0.075)	(0.086)	(0.090)	(0.074)	(0.095)	(0.071)
dsmall	0.403**	0.491***	0.468***	0.432**	0.376**	0.384**
	(0.161)	(0.159)	(0.157)	(0.187)	(0.181)	(0.177)
dmedium	0.359***	0.412***	0.388***	0.435***	0.333**	0.341**
	(0.118)	(0.117)	(0.118)	(0.142)	(0.144)	(0.137)
Prod	0.398***	0.367***	0.375***	0.413***	0.318***	0.322***
	(0.035)	(0.037)	(0.035)	(0.046)	(0.059)	(0.040)
dENVINNO						
EnvTax	0.531***	0.530***	0.526***	0.410***	0.414***	0.409***
	(0.069)	(0.069)	(0.069)	(0.078)	(0.077)	(0.081)
DemandPull	0.713***	0.720***	0.724***	0.461***	0.473***	0.474***
	(0.072)	(0.071)	(0.072)	(0.074)	(0.073)	(0.074)
GovIncentives	0.472***	0.456***	0.464***	0.155*	0.116	0.117
	(0.145)	(0.143)	(0.135)	(0.085)	(0.085)	(0.084)
WithinCO	0.223**	0.228**	0.229**			
	(0.104)	(0.102)	(0.098)			
dsmall	-0.384***	-0.383***	-0.384***	0.012	0.028	0.025
	(0.139)	(0.138)	(0.138)	(0.161)	(0.160)	(0.159)
dmedium	-0.207**	-0.207**	-0.205**	0.104	0.123	0.120
	(0.101)	(0.100)	(0.099)	(0.120)	(0.119)	(0.118)
Prod	0.061**	0.061**	0.061**	0.162***	0.164***	0.163***
	(0.028)	(0.028)	(0.029)	(0.033)	(0.033)	(0.033)
dEXP						
N. of Observations	2640			2200		
Log PseudoLikelihood	-1242.19			-963.71		
Wald Chi2	500.38***			416.48***		
dEnvInno						
N. of Observations	2570			2193		
Log PseudoLikelihood	-1524.31			-1248.64		
Wald Chi2	377.85***			362.72***		
dEXP						
N. of Observations		2570	3060		2193	2987
Log Likelihood		-2720.64	-2763.93		-2206.84	-2208.67
Rho		-0.407***	-0.313**		-0.609***	-0.602***
Wald chi2		1032.58***	1025.59***		1112.84***	1207.38***

*Note: Significance levels: *** 0.01, ** 0.05, * 0.1; sector dummies are not reported*

Table 6. Estimates by emission intensity, Model 2

	CIS2008		CIS2014	
	ESM	**Bivariate Probit**	**ESM**	**Bivariate Probit**
	b/se			
dEXP				
dENVINNO	0.568***	0.736***	0.810***	0.865**
	(0.206)	(0.176)	(0.384)	(0.344)
EnvTaxGreen	-0.223	-0.324	0.039	0.021
	(0.233)	(0.221)	(0.159)	(0.148)
EnvTaxGrey	0.171	0.133	-0.214	-0.223
	(0.120)	(0.120)	(0.167)	(0.175)
EnvTaxBrown	-0.246**	-0.332***	-0.240	-0.263*
	(0.123)	(0.120)	(0.172)	(0.158)
dsmall	0.453***	0.474***	0.400**	0.397**
	(0.157)	(0.160)	(0.186)	(0.185)
dmedium	0.382***	0.405***	0.371**	0.363**
	(0.118)	(0.117)	(0.149)	(0.148)
Prod	0.375***	0.366***	0.347***	0.339***
	(0.035)	(0.037)	(0.059)	(0.066)
dENVINNO				
EnvTaxGreen	0.634***	0.641***	0.394***	0.395***
	(0.213)	(0.229)	(0.108)	(0.106)
EnvTaxGrey	0.368***	0.371***	0.386*	0.390**
	(0.093)	(0.093)	(0.155)	(0.152)
EnvTaxBrown	0.717***	0.722***	0.553***	0.554***
	(0.112)	(0.116)	(0.141)	(0.141)
DemandPull	0.728***	0.7254***	0.489***	0.487***
	(0.072)	(0.071)	(0.075)	(0.073)
GovIncentives	0.456***	0.449***	0.135	0.131
	(0.136)	(0.143)	(0.087)	(0.086)
WithinCO	0.228**	0.227**		
	(0.097)	(0.102)		
dsmall	-0.372***	-0.372***	0.016	0.017
	(0.138)	(0.138)	(0.161)	(0.161)
dmedium	-0.202**	-0.204**	0.105	0.106
	(0.099)	(0.100)	(0.119)	(0.120)
Prod	0.062**	0.062**	0.164***	0.164***
	(0.028)	(0.028)	(0.033)	(0.033)
dEXP				
N. of Observations	3060	2570	2987	2193
Log Likelihood	-2757.60	-2715.65	-2206.08	-2203.72
Rho	-0.304**	-0.402***	-0.484**	-0.516**
Wald chi2	1022.91***	1026.29***	1092.99***	1039.33***

*Note. Significance levels: *** 0.01, ** 0.05, * 0.1; sector dummies are not reported.*

Table 7. Estimates of Direct and Total Effect of Environmental Tax on Exporting Propensity of Firms, Model 2

	All Sample	
	CIS2008	**CIS2014**
	b/se	
Bivariate Probit		
Direct Effect		
EnvTaxGreen	-0.089	0.005
	(0.064)	(0.037)
EnvTaxGrey	0.034	-0.057
	(0.030)	(0.046)
EnvTaxBrown	-0.091***	-0.068
	(0.034)	(0.042)
Total Effect		
EnvTaxGreen	-0.054	0.034
	(0.060)	(0.032)
EnvTaxGrey	0.062**	-0.032
	(0.030)	(0.044)
EnvTaxBrown	-0.051	-0.033
	(0.032)	(0.036)
ESM		
Direct Effect		
EnvTaxGreen	-0.061**	0.010**
	(0.025)	(0.005)
EnvTaxGrey	0.048**	-0.024
	(0.019)	(0.086)
EnvTaxBrown	-0.069**	-0.064**
	(0.027)	(0.027)
Total effect		
EnvTaxGreen	-0.031	0.028
	(0.019)	(0.021)
EnvTaxGrey	0.060**	-0.025*
	(0.027)	(0.015)
EnvTaxBrown	-0.033	-0.022
	(0.020)	(0.018)

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

Table 8.1 Estimates by emission intensity –Small Firms

	CIS2008				CIS2014			
	ESM		Bivariate Probit		ESM		Bivariate Probit	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
	b/se				b/se			
dEXP								
dENVINNO	0.218	0.181	0.321	0.273	0.600	0.252	0.890*	0.389
	(0.335)	(0.336)	(0.405)	(0.415)	(0.499)	(0.460)	(0.532)	(0.546)
EnvTax	0.123		0.077		-0.039		-0.143	
	(0.158)		(0.175)		(0.192)		(0.211)	
EnvTaxGreen		-0.292		-0.364		0.214		0.171
		(0.342)		(0.339)		(0.214)		(0.229)
EnvTaxGrey		0.276		0.249		0.303		0.283
		(0.182)		(0.189)		(0.285)		(0.314)
EnvTaxBrown		0.102		0.059		-0.122		-0.190
		(0.236)		(0.266)		(0.284)		(0.307)
Prod	0.383***	0.382***	0.384***	0.385***	0.389***	0.426***	0.349***	0.414***
	(0.046)	(0.046)	(0.052)	(0.052)	(0.078)	(0.065)	(0.100)	(0.075)
dENVINNO								
EnvTax	0.597***		0.598***		0.473***		0.484***	
	(0.116)		(0.117)		(0.129)		(0.129)	
EnvTaxGreen		0.834***		0.834**		0.332**		0.335**
		(0.316)		(0.327)		(0.167)		(0.170)
EnvTaxGrey		0.280*		0.280*		-0.126		-0.123
		(0.157)		(0.157)		(0.263)		(0.265)
EnvTaxBrown		0.998***		0.998***		0.988***		0.985***
		(0.201)		(0.208)		(0.234)		(0.232)
DemandPull	0.638***	0.651***	0.639***	0.652***	0.429***	0.457***	0.431***	0.463***
	(0.119)	(0.120)	(0.118)	(0.119)	(0.117)	(0.120)	(0.112)	(0.123)
GovIncentives	0.352*	0.303	0.308	0.299	0.178	0.284**	0.156	0.274*
	(0.206)	(0.204)	(0.223)	(0.225)	(0.140)	(0.138)	(0.149)	(0.150)
WithinCO	0.313	0.362*	0.344	0.356				
	(0.203)	(0.205)	(0.237)	(0.236)				
Prod	-0.001	0.000	-0.001	0.000	0.156***	0.147***	0.157***	0.147***
	(0.044)	(0.045)	(0.045)	(0.045)	(0.049)	(0.049)	(0.049)	(0.050)
N. of Observations	1213	1213	1066	1066	1316	1316	1038	1038
Log Likelihood	-1326.09	-1321.05	-1306.83	-1301.07	-1209.67	-1203.66	-1207.91	-1202.22
Rho	-0.151	-0.124	-0.214	-0.179	-0.339	-0.120	-0.521	-0.205
Wald chi2	274.80	281.06***	268.90***	271.70***	414.95***	388.42***	478.08***	403.96***

*Note. Significance levels: *** 0.01, ** 0.05, * 0.1; sector dummies are considered but not reported.*

Table 8.2 Estimates by emission intensity –Medium firms

	CIS2008				CIS2014			
	ESM		Bivariate Probit		ESM		Bivariate Probit	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
	b/se				b/se			
dEXP								
dENVINNO	0.813**	0.814**	1.049***	1.067***	0.850***	0.825*	1.120	0.831
	(0.340)	(0.325)	(0.249)	(0.248)	(0.312)	(0.476)	(0.932)	(1.066)
EnvTax	-0.195		-0.293**		-0.251*		-0.329	
	(0.146)		(0.133)		(0.133)		(0.203)	
EnvTaxGreen		-0.615		-0.825*		-0.060		-0.049
		(0.423)		(0.425)		(0.214)		(0.312)
EnvTaxGrey		0.146		0.095		-0.468*		-0.804**
		(0.198)		(0.198)		(0.279)		(0.323)
EnvTaxBrown		-0.419**		-0.552***		-0.271		-0.308
		(0.183)		(0.170)		(0.241)		(0.288)
Prod	0.471***	0.466***	0.459***	0.451***	0.358***	0.362***	0.402***	0.452***
	(0.065)	(0.064)	(0.068)	(0.067)	(0.074)	(0.079)	(0.155)	(0.154)
dENVINNO								
EnvTax	0.596***		0.605***		0.364***		0.371***	
	(0.110)		(0.110)		(0.134)		(0.136)	
EnvTaxGreen		1.312***		1.342***		0.321*		0.316*
		(0.443)		(0.488)		(0.181)		(0.174)
EnvTaxGrey		0.433***		0.436***		0.706***		0.677***
		(0.151)		(0.153)		(0.250)		(0.248)
EnvTaxBrown		0.673***		0.685***		0.288		0.282
		(0.170)		(0.172)		(0.230)		(0.230)
DemandPull	0.901***	0.904***	0.889***	0.890***	0.532***	0.532***	0.514***	0.538***
	(0.117)	(0.117)	(0.118)	(0.119)	(0.123)	(0.124)	(0.162)	(0.134)
GovIncentives	0.415*	0.425*	0.412*	0.427*	0.173	0.172	0.154	0.177
	(0.218)	(0.220)	(0.240)	(0.238)	(0.138)	(0.139)	(0.149)	(0.140)
WithinCO	0.127	0.126	0.133	0.131				
	(0.175)	(0.175)	(0.179)	(0.177)				
Prod	0.068	0.070	0.068	0.070	0.091	0.095	0.097*	0.101*
	(0.048)	(0.048)	(0.048)	(0.048)	(0.058)	(0.059)	(0.059)	(0.059)
N. of Observations	1114	1114	978	978	943	943	762	762
Log Likelihood	-1021.47	-1016.65	-998.41	-992.63	-722.04	-719.89	-710.83	-707.22
Rho	-0.394*	-0.386*	-0.526***	-0.527***	-0.545***	-0.534**	-0.706	-0.540
Wald chi2	328.47***	332.43***	356.94***	369.18***	255.94***	251.55***	1427.19***	1041.34***

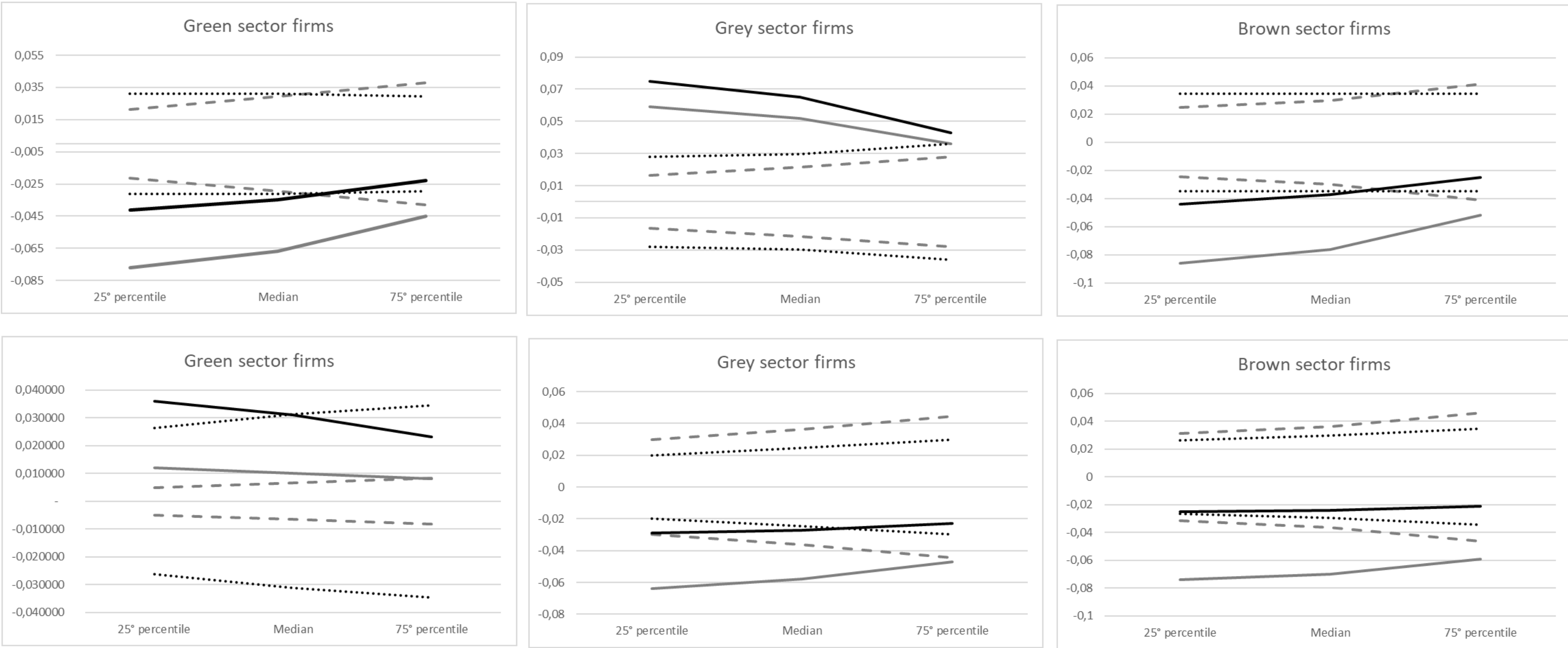
*Note. Significance levels: *** 0.01, ** 0.05, * 0.1; sector dummies are not reported*

Table 8.3 Estimates by emission intensity –Large Firms

	CIS2008				CIS2014		
	ESM		Bivariate Probit		ESM	Bivariate Probit	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 1	Model 2
	b/se				b/se		
dEXP							
dENVINNO	1.033*	0.915*	1.110***	1.082***	1.418**	1.490***	1.327***
	(0.556)	(0.544)	(0.342)	(0.391)	(0.310)	(0.426)	(0.359)
EnvTax	-0.055		-0.074		0.100	0.086	
	(0.179)		(0.173)		(0.211)	(0.218)	
EnvTaxGreen				5.207***			0.623
				(0.438)			(0.414)
EnvTaxGrey		0.045		-0.002			-0.629
		(0.275)		(0.264)			(0.581)
EnvTaxBrown		-0.338		-0.349			0.009
		(0.254)		(0.248)			(0.365)
Prod	0.133	0.140	0.123*	0.118*	0.119	0.211*	0.246**
	(0.083)	(0.084)	(0.066)	(0.069)	(0.082)	(0.109)	(0.114)
dENVINNO							
EnvTax	0.289**		0.290**		0.446**	0.451***	
	(0.142)		(0.139)		(0.199)	(0.174)	
EnvTaxGreen		-0.293		-0.475			0.527*
		(0.483)		(0.430)			(0.272)
EnvTaxGrey		0.377**		0.379**			0.145
		(0.187)		(0.186)			(0.358)
EnvTaxBrown		0.315		0.308			0.424
		(0.245)		(0.243)			(0.313)
DemandPull	0.573***	0.584***	0.575***	0.586***	0.503***	0.557***	0.569***
	(0.153)	(0.155)	(0.147)	(0.149)	(0.187)	(0.178)	(0.175)
GovIncentives	1.224**	1.219**	1.224***	1.223***	-0.112	-0.050	-0.030
	(0.497)	(0.498)	(0.462)	(0.475)	(0.213)	(0.202)	(0.193)
WithinCO	0.228	0.223	0.230	0.231			
	(0.152)	(0.155)	(0.152)	(0.153)			
Prod	0.179***	0.187***	0.178***	0.187***	0.237***	0.258***	0.267***
	(0.066)	(0.066)	(0.060)	(0.061)	(0.079)	(0.074)	(0.075)
N. of Observations	733	733	526	526	728	393	393
Log Likelihood	-387.02	-385.23	-385.35	-381.20	-243.40	-220.47	-218.71
Rho	-0.511*	-0.439	-0.548***	-0.518**	-0.613***	-0.777***	-0.701***
Wald chi2	116.70***	114.88***	162.96***	973.67***	130.98***	8706.06***	8548.94***

*Note. Significance levels: *** 0.01, ** 0.05, * 0.1; sector dummies are not reported. ESM estimates are not available due to convergence issues for CIS2014.*

Figure 1. Direct and total effect of environmental regulation by level of productivity and sector- CIS2008 and CIS2014



Note. Black and grey full lines represent the total and direct effect respectively; dotted lines define the confidence interval (90%) for total effect, while, dashed lines define the confidence interval (90%) for direct effect. First row reports CIS2008 graphs, while, second row, shows CIS2014 graphs.

Appendix B – Mathematical derivative 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

(B1) $\delta f_e = f_d k(DD)[1 - G(DD)] + f_d^* k(DF)[1 - G(DF)] + \Delta f k(\tilde{\varphi})[1 - G(\tilde{\varphi})]$

where

(B2) $k(i) = \left[\frac{\bar{\varphi}(i)}{i}\right]^{\varepsilon-1} - 1 \qquad\qquad i = DD, DF, \tilde{\varphi}$

(B3) $\bar{\varphi}(i) = \left[\frac{1}{1-G(i)} \int_i^{\infty} \varphi^{\varepsilon-1} g(\varphi) d\varphi\right]^{\frac{1}{\varepsilon-1}}$

(B4) $\Delta f = f_c + f_c^* - f_d - f_d^*$

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 (B1), we obtain

(B5) $\delta f_e = f_d\, J(DD) + f_d^*\, J(DF) + \Delta f\, J(\tilde{\varphi})$

By differentiating Equation (B5) with respect to t, we can study the effect of a change of the environmental tax on DD

(B6) $\frac{d\delta f_e}{dt} = f_d\, J'(DD) \frac{dDD}{dt} + f_d^*\, J'(DF) \frac{dDF}{dt} + \Delta f\, J'(\tilde{\varphi}) \frac{d\tilde{\varphi}}{dt} = 0$

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

(B7) $\frac{dDF}{dt} = \tau \left(\frac{f_d^*}{f_d}\right)^{\frac{1}{\varepsilon-1}} \frac{dDD}{dt}$

(B8) $\frac{d\tilde{\varphi}}{dt} = \frac{dDD}{dt} \frac{\tilde{\varphi}}{DD} - \frac{\tilde{\varphi}}{1+t}\, a$

where $a = \frac{1}{1-\left[\frac{c(1+t)}{c_C}\right]^{\varepsilon}}$. The obtained values are substituted in equation (B6) and we get

(B9) $\frac{dDD}{dt} = \frac{DD}{1+t}\, a\, b$

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.

(B10) $\frac{d\tilde{\varphi}}{dt} = \frac{\tilde{\varphi}}{1+t} \, a \, [b - 1]$

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