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ESSAYS ON TRADE, DIRECTED TECHNICAL CHANGE AND ENVIRONMENT

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Summary

In the last decades the consequences of the economic growth on the ecosystem are evident, and the environmental protection has become a crucial issue not only in natural sciences setting, but especially from an economic and political point of view. Researchers and policymakers focused the attention on the causes of pollution in order to prevent environmental degradation, and on the consequences that economic and political actions may have on the economic growth.

This work, through three different essays, attempts to debate the environmental issue in a wide prospective from different points of view. The first one regards the link between international trade and environment. In some cases, researchers agreed with the idea that trade liberalization could lead to an improvement of environmental quality, while Pollution Haven Hypothesis states that environmental regulation induces firms to relocate dirty production where the environmental regulation is less stringent. The first part of this work gives an overview of this branch of literature, explaining some studies that support and contrast these theories.

The research question of the second part concerns the international flow of hazardous waste and its drivers. Using a gravity model for trade, the article tries to underlines the role played by the relative levels of policy stringency and the technological specialization across EU-OECD countries and regions.

The last part of the present work, tries to analyse the eco-friendly innovation from a different point of view. Considering a long span of time, the essay investigates the effects that income distribution and institutions may have on the generation of environmental related patents.

Trade liberalization and environment: a survey of the literature

Abstract

This article offers a review of the literature about the relationship between trade and environment. We tried to mark the rout of the literature about this topic focusing on the different factors involved. The topic is analysed from different perspectives through the empirical contributions of the literature about this debate, starting from the role played by regulation, until the implications about capital.

1. Introduction

The economic debate has dealt with many issues over time, perhaps one of the most heated has been the openness to international trade as a driver of growth and development. The basic idea is that market specialization leads to a more efficient allocation of resources exploiting the comparative advantage. Furthermore, this allows to a widespread availability of new technologies making more competitive domestic and international markets.

In this setting the relationship between international trade and environmental quality appears significant. In some cases, the researchers agreed with the idea that trade liberalization could lead to an improvement of allocation in domestic market, for example the study conducted by Brack (1998) underlined the role of trade liberalization as a driver of a "green" specialization. On the other hand, several works tried to demonstrate the opposite result, underlining the negative role of trade liberalization in increasing environmental pollution. The global challenge is to solve the conflict between environmental degradation and economic growth due to international trade.

An important branch of literature faced this issue from different points of view. Theoretical works have tried to investigate different links between trade openness and environmental quality, and at the same time many studies have tried to validate these results through empirical analysis that conduct to different conclusions in different environmental fields. Among these theories Pollution Haven Hypothesis, that represents the major research area, suggests that relatively poorer countries could become more polluted through trade. The theoretical foundation of this idea rises from the assumption that the industry's spread depends on the normative differences about regulation stringency.

On the contrary an alternative theory considers the role of the factor endowment (Copeland and Taylor, 2004) underlining how dirty industries are relative capital-intensive, for this reason these production processes should be relocated to the relative capital-abundant developed countries. Empirical studies provided by Tobey (1990) and Jaffe et al. (1995), in fact, found that the international flows of dirtiest productions and goods are due to factor endowment motivations and not to different regulation systems.

Another important strand of literature highlights the role played by income per capita. According to the Environmental Kuznets Curve (EKC) (Grossman and Krueger, 1993) there is U-shaped relationship between a country's per capita income and its level of environmental quality, this means that if we can consider the environmental quality as a normal good (it increases with the level of the income) than trade could have a strong impact on the environment since it generated wealth and growth. The basic idea is that income growth does not increase the level of environmental degradation, but rather higher levels of income lead to an improvement in environmental quality. This means that while environmental quality deteriorates in the early stages of economic development, it improves in the later stages. Corresponding to the early stage of economic growth, the awareness of environmental problems is low or negligible and environment friendly technologies are not available (Dinda, 2004).

This aspect also underlines how in the debate between trade and environment, we cannot ignore considerations concerning the national characteristics of the countries involved, such as income, factors endowment and technological level.

The aim of this paper is to set out what we know about environmental consequences of economic growth and trade liberalization. Starting from the role of environmental policies we tried to review the existing literature by examining the importance of regulation, capital abundance, FDI and the existence of the EKC through the study of most important environmental fields[1].

The paper is organized as follow, section 2 analyses the relationship between environmental regulation and trade, while section 3 considers the link between trade and development. section

[1] As Water pollution, carbon leakage, etc.

4 gives some evidences about the role played by capital abundance, and finally section 5 concludes.

2. The fight between environmental regulation and trade

The literature in the last decades highlighted the role played by public policies in environmental field capable of influencing the trade flows. According to this strand of literature, stringent levels of regulation would prompt firms to leave the country for less strict (and hence less expensive) regulatory regimes. This is called by literature the "Pollution Haven Hypothesis" and represents the main topic at the centre of the debate about *trade liberalization* and *environmental quality*. The Pollution Haven Hypothesis (from now on PHH) posits that jurisdictions with weak environmental regulations (often the poorest countries) attract polluting industries relocating from more regulating countries. The reason is intuitive: the regulation rises the costs of polluting–intensive productions reducing their comparative advantage in those goods[2]. As we can see in the next sections there are some evidences that expanded trade may worsen environmental conditions. The odds that increased trade will have net negative environmental impacts rise if resources are mispriced (Anderson, 1998; Panayotou, 1993), in fact expanded trade can exacerbate pollution harms and natural resource management mistakes in the absence of appropriate environmental policies (Nordstrom and Vaughan, 1999)

2.1 "Pollution Haven Hypothesis" and "Environmental dumping"

According to Copeland and Taylor (2004) a rigorous difference has to be made examining the literature about PHH. The first one regards the intrinsic definition of PHH, they argued that when the stringent regulation affects the trade flows (i.e. the flow of "dirty" goods imported or exported) then we face the "pollution haven effect". Alternatively, the "Pollution Haven Hypothesis" concerns the trade patterns and the stringent environmental regulation. In fact, PHH predicts that the trade liberalization reduces trade barriers, in this way "dirty" industries shift from countries with stringent environmental regulation to countries with lax environmental regulation. These two concepts are related, in fact the pollution haven effect is necessary

[2] Following Brunnemeier and Levison (2004) the theoretical foundation of this idea that is the Heckscher-Ohlin model of international trade, which shows that countries tend to export goods whose production is based on local factors as production inputs.

condition for the existence of PHH: when PHH occurs necessarily there is a pollution haven effect[3].

Furthermore, Copeland and Taylor (2004) argued that it may be useful to make a difference between PHH and another important concept: the *environmental dumping*. According to the authors "*environmental dumping refers to a situation where pollution regulation is less stringent than it would be in the absence of strategic interaction. Alternatively, it is a situation where equilibrium pollution levels in the non-cooperative Nash equilibrium exceed those in the cooperative equilibrium"*.

The first contributions to the literature about the environmental dumping are given by Barrett (1994) and Rauscher (1991). They argued that environmental dumping refers to the strategic use of the policy and its first best levels, that can have negative welfare implication. Instead, according to the authors, PHH focuses on the difference between policy instruments across countries and how this affects trade flows, thus PHH nothing predicts about welfare levels.

Elbers and Withagens (2004) presented a theoretical model in which governments know the impacts of their environmental decisions on world prices, industry location and labour market. The traditional view of the literature about environment and international trade considers the factors' mobility as a key determinant of the relocation of productions across countries, because if factors are immobile the possibility to shift production processes abroad is limited by the availability of productive factors, this is true especially if we consider that the countries with lax regulation are the poorest ones. However, this is not the only issue related to productivity factors, because factors moving into the lax regulation regions may bring new technology or rise the host country's national income. Furthermore, Elbers and Withagen (2004) showed that, factor mobility may in some cases induce governments to increase the environmental standards because skilled workers have a higher environmental awareness. Considering standard two-sector model with a monopolistically competitive manufacturing sector with increasing returns and a perfectly competitive agricultural sector with constant returns, the authors found that in this context factor mobility can reduce the tendency to concentrate polluting activities in one country. Lax pollution regulation rises the return to skilled labour and works towards the agglomeration of manufacturing in one country, the concentration of industry also raises local pollution levels. Since skilled workers also care about environmental quality, the increased local pollution lowers the welfare of skilled workers and works against this concentration. Thus, even

[3] Taylor (2006) highlighted the necessity to separating this two concepts.

if the concentration of manufacturing in one country is a potential equilibrium (under some parameter values), the likelihood of the concentration is lessened by the introduction of environmental concerns. Concluding they showed that altering the degree of factor mobility does not necessarily imply a negative situation increasing pollution haven effect.

2.2. Environmental policies, trade flows and environmental quality: some empirical evidences

Several studies focused the attention on the effect of a regulatory regime on production and pollution levels, especially on air and water pollution.

Starting from 1992 Lucas, Wheerler and Hettige used the IPPS[4] data to examine whether the toxic intensity of production changed with economic growth for 80 countries between 1960 and 1980. Using a pooled cross-sectional model, they found that toxic intensity of output increased especially in closed economies while open economies shifted toward cleaner industries. One year later Birdsall and Wheeler (1993) arrived at similar result studying the change in toxic intensity in Latin America. Both works focused on income levels and openness economy ignoring the role of other factors, such as resource endowments. Furthermore, problems of omitted variables bias are possible because of cross-sectional pooled data[5].

Another branch of literature considered that international trade can endogenously affect environmental policy, underlining a reverse causality between them. For example, Bommer (1998) defined NAFTA as a free trade agreement that potentially improves environmental situation. Indeed, the endogeneity effect changes considerably the results. Levinson and Taylor (2003) enumerated many mechanisms by which trade can affect pollution abatement costs (from now on PAC), including terms of trade effects, unobserved heterogeneity and natural resource endowments, etc. They, studying a panel dataset through two stage least square model, found that endogeneity as a positive and significant role. Ederington and Minier (2003) evaluated the U.S. net imports from 1978 to 1992 estimating three-stage least square model, they showed that pollution abatement costs have a significant and positive effect on imports, even if results are sensitive to the instruments chosen. Ederington, Levinson, and Minier (2004) tried to estimate U.S. net imports by 4-digit SIC code over the same period of Ederington and Minier (2003)

[4] The World Bank industrial pollution projection system (IPPS).

[5] According to Copeland and Taylor (2004) most of the literature belonging to the period before 1997 considering cross-sectional data is unable to account for unobserved heterogeneity, usually this literature assumes pollution as an exogeneous variable.

using year and industries fixed effects. In spite of different evaluation, they confirmed the results.

2.3 The problem of externalities

Perhaps, the most debated issue around the question regards negative externalities caused by the movement of pollutants[6] that have some long-distance impacts, for this reason the need to control this effect makes necessary the introduction of punctual policy to internalize the negative externalities. In fact, uninternalized externalities not only lead to environmental degradation, but also threaten market failures that will diminish the efficiency of international economic exchanges, reduce gains from trade, and lower social welfare. Some mechanism for promoting collective action and for disciplining free riders is therefore required (Baumol and Oates, 1988).

Same studies have demonstrated that other forces work harder. Dean (2002) carried out two-least square analysis on the water pollution discharge growth in China using as control variables countries' specific characteristics and policy measures. What Dean (2002) tried to demonstrate is an increase of water pollution in the case of free trade, but simultaneously this effect is mitigated by the income growth generated by trade, finally the total effect is positive at country level. This means that the gain from trade obtained in terms of economic growth is so great that it outweighs the loss of welfare caused by water pollution.

The policy debate has focused the attention especially on the normative standards about the carbon dioxide emissions[7]. The logic that emerges from the literature regards the possibility of a unilateral policy introduced by countries that controls CO2. The presence of a carbon tax could shift the comparative advantage of energy intensive productions from the countries with stringent policy to the countries with a lax normative system, this phenomenon is called in the literature as "*carbon leakage*". One of the most important channel through this mechanism works is the changing in relative price: the carbon tax increases the cost of production so the energy-intensive productions shift away toward countries where the energy consumption is not taxed, generating here an increase of total emissions. The result is a distortive effect in terms of

[6] Air pollutants as sulfur dioxide and carbon dioxide, and water pollutants.

[7] The cap-and-trade scheme, denominated EU Emission Trading Scheme (ETS), started with a pilot phase from 2005 to 2007, followed by a second trading period (2008–2012). The current debate concerns the new rules introduced in 2008 on the ETS third trading period (2013–2020). On the 2008 ETS reform (the so-called 20-20-20 package), see http://ec.europa.eu/environment/climat/pdf/draft proposal e_ort sharing.pdf. On the sectors included in ETS see McKinsey (2006).

displacement of production processes from countries with abating policies to countries where no climate policies are in force (Antimiani et al., 2013).

Carbon leakage is typically treated using computable general equilibrium models (CGE), that represent an *ex ante* analysis compering the emission increase in non-Kyoto countries to emission increase in Kyoto countries. In this setting the works provided by Felder and Rutherford (1993) and Bernstein et al., (1999) found a moderate leakage, in contrast Burniaux and Martins (2000), Babiker (2005) found a significant leakage[8]. In 2008 the Word Bank tried to conduct an *ex post* analysis employing a gravity model to test the effect of carbon taxes on bilateral goods flows, the findings showed the absence of the leakage. In contrast, Aichele and Felbermayr (2011) tried to estimate in a panel context a similar gravity model for the CO2 content of trade between Kyoto e non-Kyoto countries, in this case the evidences suggest that the carbon imports are increase as well as the total intensity of the imports (see Table 1).

[8] Note that CGE simulations differ because of different assumption or parametrization.

Table 1 – Summary of the literature

Authors	***Empirical study***	***Results***
Dean (2002)	Two-least square analysis on the water pollution discharge growth in China using as control variables countries' specific characteristics and policy measures	The level of water pollution increases but this effect is mitigated by the income growth generated through the trade
Lucas, Wheerler and Hettige (1992)	Pooled cross-sectional model analysing the correlation between toxic intensity of production and economic growth	Toxic intensity of output increased especially in closed economies. Open economies shifted toward cleaner industries.
Birdsall and Wheeler (1993)	Correlation between toxic intensity of production in Latin America and economic growth	Similar results provided by Lucas, Wheerler and Hettige (1992). Openness encourages cleaner industry.
Mani and Wheeler (1998)	Through graphical approach, the work considers the share of "dirty" goods produced in OECD, South America and Asia from 1960 to 1995.	Decreasing number of polluting industries in OECD countries and increasing in Asia and South America
Levinson and Taylor (2003)	The work analyses panel dataset about U.S. net export in order to study how trade can affects other factors (i.e. terms of trade effects, unobserved heterogeneity, industry size, etc.)	The work stresses the role of endogeneity
Ederington and Minier (2003)	Evaluation about U.S. net imports from 1978 to 1992	Pollution abatement costs have a significant and positive effect on imports
Ederington, Levinson, and Minier (2004)	U.S. net imports by 4-digit SIC code over the period 1978-1992 using fixed effects	The work confirms the previous results by Ederington and Minier (2003)
Antweiler, Copeland, and Taylor (2001)	The authors evaluate the model through fixed effects analysis on sulfur dioxide (SO2) concentration over the period 1971-1996 in 40 different countries.	The rise in trade generates a decrease in SO2 concentrations.

Berman and Bui (2001)	Effect of policy stringency on changes in employment in refineries in Los Angeles between 1979 and 1992.	They find no evidence that regulations have a negative effect on employment.
Word Bank (2008)	*Ex post* analysis through gravity model for trade to test the effect of carbon taxes on bilateral goods flow	Absence of carbon leakage
Aichele and Felbermayr (2011)	*Ex post* analysis using gravity model CO2 content of trade	The results suggest the presence of carbon leakage

3. Trade, environment and development

3.1 Foreign directed investment and environmental consequences

The standard approach to FDI inflows to developing countries is based on endogenous growth theory where FDI increases the capital stock and technological know-how, which in turn rises income and labor productivity in the host country, this could result in higher GDP and tax revenues. There is an important branch of literature that links the environmental pollution and the foreign directed investment. Foreign direct investment (FDI) has played an important role in promoting economic growth, especially in developing countries, which have reduced barriers to FDI and improved their business climates to attract FDI. In fact, according to Harrison (1994) foreign direct investment is an important source of advanced technology in developing nations, but although FDI helps economic development, they may lead to more environmental damage.

In this setting two different hypothesis are opposed each other. According to the pollution haven hypothesis, weak environmental regulation in a host country may attract inward FDI by profit-driven companies that want to avoid the compliance costs due to regulation (Jensen, 1996). On the other hand, FDI should have positive environmental spillovers very similar to its positive productivity spillovers. These positive externalities are largely due to the fact that FDI has the potential of transferring superior technologies from more developed to less developed economies. This hypothesis is called the FDI *"halo effect*". Several studies consider the role of FDI taking different positions.

3.1 FDI flows are influenced by environmental policy

In 1997 Eskeland and Harrison conducted an empirical analysis that connected the U.S. pollution abatement costs to the FDI flows. They showed the absence of a significant effect in U.S. on both outbound and inbound FDI. This means they found no significant correlation between environmental regulation in industrialized countries and foreign investment in developing countries. This result seems to reject the role of FDI as a way to avoid the high compliance costs due to the regulation.

On the contrary, some years later Smarzynska and Wei (2001) tried to estimate the role of inbound FDI in transition economies using the U.S. sectoral emission intensity as a proxy of pollution intensity. Despite the estimation problem due to the instrument selected as a proxy of pollution intensity, the result highlights that FDI are correlated to the environmental standards, although the effect is relative weak. The same result is provided by Keller and Levinson in 2002, they starting from the assumption that the largest exporters of polluting goods are not caused by environmental policy alone but also by differences in economic activities. They conducted a panel analysis over the period 1977-1994 considering the foreign directed investment inflows in U.S. and measuring state pollution abatement costs from the PACE[9] data, adjusted in order to consider each state's industrial composition. This allows to an estimation of PAC industry by industry evaluating compliance regulatory costs for each of industry considered. In this way they have build an index that compares the PAC adjusted for industrial composition in each state. The work provides a robust result underlining that pollution abatement costs have a significant but modest deterrent effect on the value and count of new foreign investment. A doubling of industry-adjusted index is associated with a less than 10% decrease in foreign direct investments (Keller and Levinson, 2002). Also, Chung (2014) analyzing FDI outflows to 50 host countries in 121 industries over the period 2000–2007, in which South Korea introduced stronger environmental standards. The estimation considers a difference-in-difference strategy on intensive and extensive margin showing the presence of dirty flows productions to lax environmental policy countries.

Hoffman et al. (2005) have given an important contribution to this strand of literature. They tested the Granger causality on pollution and FDI data introducing income differentiation among countries. The 112 countries, analyzed for the period 1971 to 1999, are classified in low, middle and high-income using the World Development indicators in order to account for the dimension of the economy. FDI are measured by the net inflows in US dollars, while the pollution is proxied by the CO2 emission, that is considered to be the primary greenhouse gas responsible for global warming; its regulation has been an important inter-governmental issue as in Talukdar and Meisner (2001). The result they showed is a very significant from our point of view. They found an important causality with respect to low-income countries that seems to be pollution havens, maybe because they do not have other characteristic to attract FDI, so lax environmental policy represents the only instrument at their disposal. This intuition is supported by the absence of a positive causality in the case of middle and high-income countries.

In this context it seems to be necessary to consider how important is the dimension of the market within the strategic choices' bundle that companies have at their disposal. This means to investigate not only on the difference between environmental regulation systems, but also on what happens when is the largest one (or the smaller one) that introduces the stringent

[9] The Personal Assessment of the College Environment (PACE) is an innovative survey that allows institutions to easily assess their progress and highlight areas for growth, define areas needing change or improvement, and set the stage for more in-depth strategic planning. https://nilie.ncsu.edu/nilie/pace-survey/survey-instrument/

regulation. In a theoretical model Sanna-Randaccio and Sestini (2012) showed that when the strongest measures are introduced by the largest country, and when the transport costs are high enough, then the probability that companies relocate via FDI is inversely proportional to the level of market asymmetry between the two markets. This result suggests that the environmental rules should consider the market size of countries involved.

3.2 FDI between economic growth and environmental damage

As the theory about the *"halo effect"* states in some cases the spillover effect of the FDI could be large enough to counterbalance, or even to outweigh, the effect of the environmental damage.

3.2.1 FDI, CO_2 emissions and energy intensity

Talukdar and Meisner (2001) tried to give a proof about the positive effect of FDI, analyzing the relationship between CO2 emissions per capita, considered a proxy for the environment, with various institutional and structural dimensions such as the scope of financial market, industrial sector composition, and the level of FDI. The results show that the higher degree of private sector involvement in a developing economy, the lower is its environmental degradation. A well-functioning domestic capital market and the participation by developed economies in its private sector development further reduce environmental degradation. The negative value for FDI suggests that foreign direct investment in an economy is likely to have a positive impact on the environment supporting in this way the *"halo effect"*. Hence, this highlights the role of foreign direct investments as a driver for advanced and cleaner environmental technologies in developing countries. This opinion is confirmed also in the case of energy intensity, in fact Mielnika and Goldemberg (2002), analyzing 20 countries over the period 1970–1998, they tried to connect the energy intensity and FDI. The result seems to support the basic idea that the use of modern technologies diffused via FDI allow to a decline of energy intensity.

At a different result arrives the contribution of Grimes and Kentor (2003), the analysis appears clear and quite simple. They used a panel regression over the period 1980-1995 in order to study connection between the increase of CO2 in less developed countries with respect the FDI flows. The empirical evidences show that foreign capital penetration in 1980 has a significant positive effect on growth in total CO2 emissions, finding in the same time no effect of domestic investment on CO2 emissions.

In recent years Hakimi and Hamdi (2016) showed some evidences in favor of the negative role of FDI. Using a time series from 1971 to 2013, they investigated the possible impact of trade liberalization on environmental quality in Tunisia and Morocco. The study founded a bidirectional causality between FDI and emission of CO2, this means that the inflows to these countries is not clean and they regard environmentally harmful activities. The results of this paper appear very significant because, on one hand the study provides evidence about trade liberalization as a boost for the economic growth in both countries considered (positive relationship between trade and GDP), but on the other hand this growth seems to be harmful for the environment. The same results had already appeared in the case of India in 2009, when Acharyya conducted for this developed country a quite similar analysis over the period 1980-2003. He found a statistically significant long run positive, but marginal, impact of FDI inflow on GDP growth. On the other hand, the long run growth impact of FDI inflow on CO2 emissions is quite large. So this not confirms the positive effect of FDI but from all this strand of literature presented above appears quite clear the FDI "*potential*" role in achieving green growth goals (Lee, 2013).

3.3 Location decisions: empirical results

The branch of literature analyzed above suggests that, maybe, also the nature of investment might matter in this debate. Given a comparable data some studies focused the attention on industry location decision, looking at the problem from a more physical point of view considering what is the role of an environmental with respect the other national characteristics such as level of wages, taxation, unionization and so on. Studies on this topic started from the early '80 years but in this survey, we decide to give a focus on more recently ones. In 2000 List and Co through a theoretical and empirical analysis found that the effect of environmental rules is small compared to other jurisdiction factors. In this setting it might be important to distinguish what happens in the case of developing countries, Mani, Pargal, and Huq (1996) used India as case study compering two level of regulatory stringency: the level of environmental spending and the enforcement. They found an insignificant effect played by enforcement while is positive the role of environmental spending, maybe because a high environmental spending means a country with durable an stable good governments. In the same year Levinson (1996) conducted an empirical work using PAC as a proxy of stringency, his analysis considered the new plants opening and not the closing ones for several reasons[10]. The result he found is positive, PAC

[10] Levison (1996) argued that the most obvious reason is the firm decides to close and to move to another location only if the compliance costs to the normative are higher than the cost of the move. This means that the location decision for the oldest firms is insensitive to the small differences in regulation.

could influence the decision about new plants opening, but the standard deviation shows a very small effect.

According to Brunnermeier and Levison (2004) all these studies suffer because, using cross-sectional analysis, they ignore the importance of unobserved omitted variables. Henderson (1996) tried to consider this problem studying the role played by air quality regulation on the number of plants through a panel data analysis. The findings showed a pollution haven effect: maintaining other things equal, regulation appear as a deterrent for the new and oldest plants.

3.4 The role of globalization

Existing literature identifies international trade as a factor capable of influencing the EKC, according to which, after an initially period where development harms the environmental quality, the degradation declines as the income increases up to a threshold, beyond it further income growth would be a benefit for the environment.

As explained above researchers appear divided about the way, positive or negative, in which trade can affect the environment. In particular this relationship seems to be contradictory, on one hand it could happen that pollution from polluted productions decrease in riches country and increase in the poorest one, as explained by the PHH, but on the other hand trade could improve the environmental conditions, because as income rises through trade, regulation becomes more stringent enhancing clean innovation and reducing pollution, this means that developing countries will automatically become cleaner as their economies grow (Harbaugh et al., 2001).

Several empirical works tried to demonstrate the existence of inverse-U-shaped pollution-income pattern. In 2005, Paudel et al. investigated the EKC on water pollution using US data and finding the threshold within the range \$10241– \$12993, \$6636–\$13877, and \$6467–\$12758 for nitrogen, phosphorus, and dissolved oxygen, respectively. The existence of EKC is tasted by Harbaugh et al. in 2001 considering air pollution and income data in US. Other studies highlighted mixed results about the shape of the relation between pollution and income level (Beede and Wheeler, 1992; Hettige et al., 2000b).

As suggested by literature (Martin and Wheeler, 1992; Reppelin-Hill, 1999), the diffusion of technologies in open markets foster the innovation of clean technologies even in developing countries, that, after the first stages in which pollution increases, could improve their environmental condition also by financing appropriate training, policy reforms, information collection and public environmental education (Desgupta et al. 2002). In 2001, Wheeler argued that international competition could improve the environmental quality of poorest countries because it increases investments in new clean technologies and employment fostering in this way the environmental awareness. This means that globalization, increasing national income, seems to be a factor reducing pollution. Developing countries, exploiting “dirty” inflows investments from richest and developed countries, could rise their national income up to the turner point, beyond that environmental quality improves with the income growth (see Table 2).

Table 2 – Summary of the literature

Authors	***Empirical study***	***Results***
Eskeland and Harrison (1997)	Empirical analysis that connected the U.S. pollution abatement cost to the FDI flows.	They showed the absence of a significant effect in U.S. on both outbound and inbound FDI.
Smarzynska and Wei (2001)	The study considers inbound FDI in transition economies using the U.S. sectoral emission intensity as a proxy of pollution intensity	The result highlights that FDI are discouraged by stringent environmental regulation.
Keller and Levinson (2002)	Panel analysis over the period 1977-1994 considering the foreign directed investment inflows in U.S. and measuring PAC as a proxy of pollution	PAC have a significant but modest deterrent effect on the value and count of new foreign investment.
Talukdar and Meisner (2001)	The paper studies the correlation between CO2 emissions, structural variable and FDI	The value for FDI appears negative suggesting a positive impact of FDI on the environment
Hoffman et al. (2005)	Granger causality on pollution and FDI data introducing income differentiation among countries. 112 countries over the period 1971-1999	The evidence shows low-income countries seems to be pollution havens
Hakimi and Hamdi (2016)	Using a time series from 1971 to 2013, the work investigates the possible impact of trade liberalization on environmental quality in Tunisia and Morocco	Bidirectional causality between FDI and emission of CO2, so the inflows is not clean.
Chung (2014)	FDI outflows from South Korea to 50 host countries in 121 industries over the period 2000–2007 using diff-in-diff estimation	The estimation shows dirty flows productions to lax environmental policy countries.

List and Co (2000)	Through cross-sectional conditional logit analysis, analyses the location of foreign-owned manufacturing plant in U.S. considering regulatory expenditure and other country's characteristics	Coefficients are statistically significant, but the effect of environmental regulation is relatively small compared to the effect of other factors.
Mani, Pargal, and Huq (1996)	India case of study: compering of two level of regulatory stringency: environmental spending and enforcement	There is an insignificant effect played by enforcement while is positive the role of environmental spending
Levinson (1996)	Empirical work using PAC as a proxy of stringency and new plants opening	PAC could influence the decision of new plants opening but in a small way
Henderson (1996)	Panel analysis that connects air quality regulation and the number of plants	Stringent regulation is a factor capable of influencing the number of plants
Paudel et al. (2005)	The work investigated the EKC on water pollution using US data using parametric and semiparametric models	The evidence shows the presence of EKC and the threshold within the range $10241–$12993, $6636–$13877, and $6467–$12758 for nitrogen, phosphorus, and dissolved oxygen, respectively.
Mielnika and Goldemberg (2002)	The study analyses the connection between energy intensity and FDI about 20 countries over the period 1970–1998	The result shows a decline of energy intensity via FDI
Grimes and Kentor (2003),	Over the period 1980-1995 the study considers the growth of CO2 of 20 less developed countries and FDI	FDI have an important effect on CO2 growth
Acharyya (2009)	Effect of FDI on CO2 emission and on GDP over the period 1980-2003 in India	There is a statistically effect of FDI on GDP but this effect is smaller than the effect between FDI and CO2 emissions.

Harbaugh et al. (2002)	The study considers the relationship between air pollution and income data in US	There is little empirical support for an inverted-U-shaped relationship between several important air pollutants and national

4. The role of capital abundance

If a branch of this literature explained in the previous sections argues the effect of trade liberalization necessarily leads to an effect of displacement of "dirty" goods and productions towards developing countries, another part of the theory states that probably this effect is mitigated or is almost absent thanks to the important role played by the capital abundance.

Several works have demonstrated trade flows depend primarily on capital intensity and other inputs to production, rather than on differences in pollution abatement costs. This leads to high-income nations (the developed countries) having a comparative advantage in many dirtier industries as their capital abundance more than offsets their higher regulatory costs (Baggs, 2009). For instance, Tobey (1990) in his empirical analysis found that the stringent environmental regulations imposed on industries in the late 1960s and early 1970s by most industrialized countries have not measurably affected international trade patterns in the most polluting industries. Tobey (1990) applied Hecksher-Ohlin model for an empirical test on five of pollution-intensive industries, and in this case the distribution of "dirty" industries across countries was not changed, in this way the presence of a regulation has not affected the trade patterns. Similarly, three years later also Grossman and Krueger (1993) analyzed the trade patterns between US and Mexico examining the correlations with industry factor intensities, tariff rates and pollution abatement costs. Their results have demonstrated the factors influencing the trade patterns are the same recognized by the traditional literature, i.e. labor and capital intensity, while differences due to environmental regulation are very small.

Perhaps, one of the most important contribution to this strand of literature is given by Antweiler, Copeland, and Taylor (2001) studied the effect of trade on the environment from both theoretical and empirical point of view. The effects of economic growth on trade can be broken down into three effects. "Technique" effects arise from the tendency toward cleaner production processes as wealth increases and trade expands access to better technologies and environmental "best practices." "Composition" effects involve a shift in preferences toward cleaner goods. "Scale" effects refer to increased pollution due to expanded economic activity and greater consumption made possible by more wealth (Etsy, 2001). They evaluated the model through fixed effects analysis on sulfur dioxide (SO2) concentration over the period 1971-1996 in 40 different countries. Combining composition, scale and technique effects[11], they showed that the rise in trade could generate a decrease in SO2 concentrations.

[11] In practise, technique and composition effect together outweigh the scale effect.

5. Conclusion and remarks

This paper reviews a number of studies on international trade and environmental implications. The debate between these two topics continues to be fierce and heated, despite the vast research involved. Several studies agree on the negative role of international trade, which pushes "dirty" production and products towards countries with less stringent environmental regulations exacerbating their living conditions. On the other hand, there are many factors that identify international trade as a factor that can stimulate growth and improve environmental degradation. This literature shows that there are subtle and weak interactions between international trade and environmental policy which, especially in some aspects, seem to be lacking and unclear.

The effect of international trade varies not only from country to country, but especially in relation to different environmental research fields. In this regard, we suggest an in-depth analysis of the consequences of international trade on the various pollutants. The analysis of the literature suggests that issues such as water pollution and waste still need to be debated in depth. Analysing the literature we have realised how far the consequences of the topics dealt with can give different results depending on the environmental fields in which they are studied. While the literature has focused on the one hand mainly on pollution factors affecting air quality (less on water quality), the presence of studies on the commercial flows of waste is marginal, although it has increased disproportionately in recent decades. The absence, or rather the scarcity, of studies on some subjects prevents a knowledge of the phenomenon as a whole and gives us an incomplete picture of the relationship that underlies environment and trade.

From this perspective, it would seem clear that environmental degradation and its implications for international trade is currently a multi-faceted problem requiring combined actions. Global environmental measures affecting the issues of trade between countries require more scrutiny (Jayadevappa and Chhatre 2000), especially in relation to the consequences in terms of environmental damage.

Further empirical works should be to categorize the consequences of international trade for different pollutants in different countries. Rather than trying to estimate the universal status of environmental damage, it would be useful to analyse what common features are shared by pollutants and countries where emissions are decreasing or increasing with trade, in order to draw more appreciate policy implications.

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Drivers of international shipments of hazardous waste: the role of policy and technology endowment

Abstract

Using a gravity model for trade, this work analyzes the factors influencing the patterns of international hazardous waste flows. We carried out a *country* and *regional* empirical analysis relying on newly available data reported in the E-PRTR (*European Pollutant Release and Transfer Registry*) for EU-OECD countries over the period 2007 to 2014. Exploiting a consolidated empirical framework, we test two empirical hypotheses: firstly, we explicitly assess if, according to the *pollution heaven hypothesis* (PHH), the relative levels of environmental policies across countries are an important determinant of hazardous waste trade, and secondly, we test if technological specialization, proxied here by a technology-specific patent stock, can be considered as a *pull* factor capable to influence the patterns of international trade of hazardous waste.

1. Introduction

In the last two decades, trade liberalisation and the increasing trend in consumption have led to a rapid upsurge in waste shipments across borders. More specifically, export of all wastes has raised from 6.3 million tonnes in 2001 to 18.8 million tonnes in 2014, while export of hazardous waste has increased by 55 % over the same period, with a peak of 8.1 million of tonnes in 2007[12].

Trading waste have obviously several relevant environmental and economic implications for both national and regional governments. If from the one hand, in fact, free trade could generate an equilibrium in which waste is treated were it is economically more convenient, from the one hand, there is the risks that shipments may results in an uncontrolled environmental dumping driven by differentials in environmental policy stringency. Consequently,

[12] Source: Eurostat

understanding which factors shape waste flows across countries and regions, can shed a light on the mechanics of this complex phenomena and help to design more efficient policy tools.

The economic literature highlights as there are two main mechanisms behind the relationship between trade and the environment. Firstly, Copeland and Taylor (1997), studies the effect of income and capital endowment differential on trade of dirty goods, and shows that if capital endowment represents the main difference between two countries, then the richest, with capital intensive production, becomes net exporter of dirty goods, and trade reduces world pollution. This will result in the emergence of pollution heaven. In contrast, if income differential between countries dominates, then trade may result in both the creation of pollution heaven and in an increase in world pollution.

According to this framework, free trade reallocates dirty productions in poorest countries. Secondly, also the cross-country heterogeneity of environmental policies can play role in shaping international trade (Ederington and Minier, 2003; Chintrakarn and Millimet, 2006). The intuition behind this mechanism is that the introduction of a specific policy places an additional cost to domestic firms that could lead to a loss of international competitiveness. The regulation would thus induce firms to relocate pollution-intensive productions abroad or to import pollution-intensive goods from countries with lax environmental regulation, because the compliance with environmental standards requires radical solutions (in terms of clean product and process) that increase the marginal cost of production. This mechanism is generally known in literature as "*Pollution Haven Hypothesis"*.

In the specific field of waste, there are only a few contributions studying the pattern of international trade. The early contribution of Baggs (2009) focuses on the role of countries capital abundance in shaping the trade of hazardous waste. This work start by the observation that capital intensive industries are the biggest producers of hazardous waste and tend to be localised in wealthiest countries with more stringent regulation. Therefore, high income countries generally have a comparative advantage in dirtiest industries (i.e. activities that generate large amounts of hazardous waste and activities aimed at disposing and recovering these hazardous waste). This capital abundance would predict that transboundary waste flows should go from lower income countries to higher income ones, so factor endowment could more than compensate the impact (opposite in sign) of environmental regulation.

Nevertheless, this analysis, does not directly account for the role of environmental policies. More recently, Kellenberg (2012) shows that different intensity of environmental policies, altering the relative marginal cost of abatement of national firms, is the main driver of municipal solid waste trade. In this work, however, the role of capital endowment is mostly overlooked.

In the present article, we focused specifically on hazardous international waste flows. Hazardous waste is defined in Annex III of Directive 2008/98/EC. The difference between hazardous and non-hazardous waste is based on the system of classification and labelling of dangerous substances and preparations. In general, waste that poses threats to the environment and public healthy, in terms of toxicity, corrosivity, ignitability and reactivity, is defined hazardous.

The choice of focusing on hazardous waste comes from different factors. Hazardous waste, requires more complex and advance disposal technologies with respect to non-hazardous, making them more suitable to test the role of capital abundance in shaping trade flows. Similarly, the sector is also highly regulated, allowing us to test for the presence of pollution heaven. In fact, the increasing amount of waste shipped attracted broad media attention, rising public awareness and placing more pressure on policy makers in this arena (Albers, 2015).

This analysis expands the existing literature in several directions. Firstly, with respect to Baggs (2009), which analysis dates back to the period 1994-97, we exploit a richer and updated dataset. In particular, we employed the E-PRTR register (http://prtr.ec.europa.eu/), which allowed us to construct a panel dataset including bilateral hazardous waste flows at plant level for OECD-EU countries from 2007 to 2014.

Secondly, thanks to this new rich set of information, we are able to complement the country level analysis with an investigation of transboundary hazardous waste flows among single firms, controlling for an host of factors at the NUTs 2 level. The value added of this second steps of analysis is manifold. On the one hand, it enriches the baseline specification testing for the role of some relevant regional characteristics like specialisation in waste treatment and openness to trade, while on the other hand it provides a robustness tests of our macro results adopting a different perspective.

Thirdly, exploiting an *ad hoc* patent stock at firm level, we are able to account for capital abundance in a more reliable way with respect to Baggs (2009). More specifically, merging the E-PRTR register with patent data[13] we are able to create waste specific index of capital

[13] Data are taken from the European Patent Office.

endowments at both country level (for the country analysis) and plant level (for the regional analysis).

Finally, we also test explicitly for the role of environmental policies, creating a variable capable to account directly for the effect of a difference in the level of environmental policy between two countries, and giving a precise test of the pollution haven hypothesis.

The Paper is organised as follow Section 2 reviews the existing literature relevant to our topic. Section 3 introduces data and Section 4 gives descriptive evidences of the phenomena. Section 5 presents empirical model and results while Section 6 is dedicated to the regional analysis. Section 7 concludes the paper.

2. Context and conceptual framework

Waste and their shipments are regulated by a complex mix of local, national and international policies. When it comes to the shipment of hazardous waste, the most important piece of legislation is the Basel Convention, according to which trade barriers seem to be necessary in order to prevent transfer of hazardous waste while minimizing the toxicity of waste generated. The Basel Convention was adopted by 184 countries and the European Union (Haiti and USA have signed but not ratified it) on 22 March 1989 and entered into force on 5 May 1992. His objective is to protect human health and the environment from the toxic effects of hazardous waste. In particular, the convention pursues: (1) the reduction of hazardous waste generation; (2) the restriction of transboundary movement; (3) a regulatory system for that cases where movements are permissible. The last one objective is based on the idea of prior information consent, it requires the track of every transaction.

The European policy framework, however, seems to go in a different direction, and supports the principle that the disposal of hazardous waste in more technologically efficient countries can have a good effect on the environment. This represent, in a sense a change in the political paradigm. If the Basel convention, in fact, wanted to protect low/income country to became pollution heaven, in the EU the political guideline is that waste should be treated where the facility has the best recovery or recycling process. (European Commission, 2016).

Nevertheless, waste policies are very heterogeneous across OECD countries, and these differences tend to be persistent across time (Nicolli, 2012). Obviously, this differential in environmental policy stringency can influence significantly the relative abatement cost of two partner countries, and consequently facilitate the emergence of the so-called "*Waste Haven Effect"*. The mechanism in play is rather simple: being hazardous waste management a capital intensive activity, with large fixed and sunk cost, it is less likely, with respect to other sectors, that firms decide to offshore polluting activities in order to comply with environmental regulations (Ederington, Lenvinson and Miner 2004)[14]. Hence the central point of "waste shipment" is that for many countries the marginal cost of exporting waste is smaller than the cost of building new waste facilities at home or offshoring the production facilities that are responsible for the generation of waste.

As a consequence, the first research hypothesis read as follow:

H1: waste exports respond to increased stringency of environmental regulation.

In order to test for this hypothesis, in this paper we constructed firstly an ad hoc policy index, and then we create a measure of the policy differential across every possible country pair.

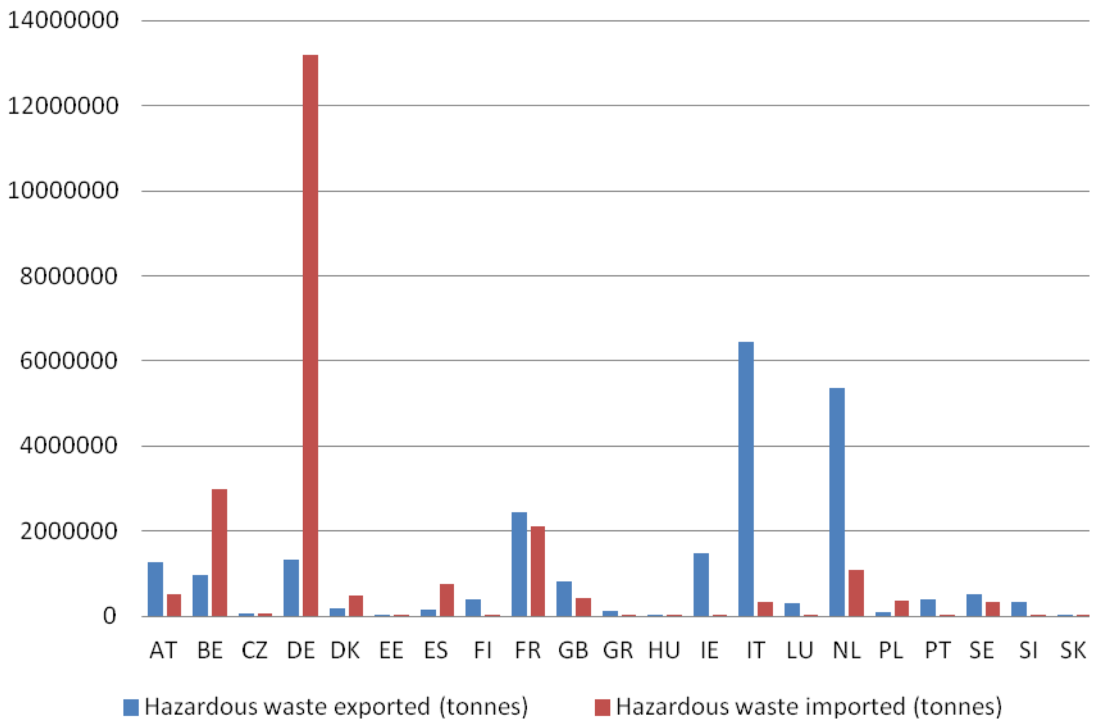
According to the contribution in Baggs (2009) transboundary waste flows could also be the results of a country specialization. His intuition is rather simple. Since the contribution of Antweiler et el. (2001), economic literature suggests that comparative advantage in dirty industries generally derive from capital abundance, which often drives trade more than pollution abatement costs (Krueger, 1993). This mechanism, imply that often, in high-income countries, the effect of comparative advantage in dirty production on trade, more than offset the role plays by higher regulatory costs, or the so-called pollution heaven hypothesis. Being the disposal of hazardous waste a capital intense activity, it is reasonable to assume that differential in capital endowment can act as an attractive factor for waste trade. A simple descriptive exercise, presented in Figure 1, gives preliminary support to Baggs's theoretical predictions. The figure shows the amount (in tonnes) of hazardous waste exported and imported by OECD EU countries over the period 2007-2014. As visible, Germany is the biggest net importer of hazardous waste despite being a country with a stringent set of environmental policies. According to this logic, the reason behind this result can be found in its high level of capital abundance.

[14] See also Cole and Elliot (2005) and Cole and Okubo (2010)

As a consequence, one can argue that a country specialisation in the disposal of dirty goods, being a direct consequence of an high capital abundance, is a factor which can attract shipment of hazardous waste. Consequently, the second research hypothesis can be read as follow:

H2: *Transboundary waste flows are the result of a country (region) specialisation in waste treatment technologies.*

Figure 1-Total import and export of waste by country



2. Data and descriptive statistics

Panel data on transboundary hazardous waste flows are obtained from the E-PRTR database (*European Pollutant Release and Transfer Registry*) for EU countries over the period 2007 to 2014.

Introduced by Regulation (EC) 166/2006, the E-PRTR is the European-wide register that collects environmental data for about 30.000 industrial facilities and covers 65 sectors. For what concerns hazardous waste, E-PRTR includes information on international waste shipment of hazardous waste for those facilities that transfer off-site (either in the home country or abroad) 2 tonnes or more of hazardous waste per year.

To measure the relative stringency of waste-related environmental policies, we build a specific policy indicator. The policy index is the result of a two-step process representing respectively: (1) the systemization and weighting of the different types of government policies to manage waste, and (2) their joint adoption per country per year. The indicator is based on the "*OECD database on Policy Instruments for the Environment*". [15] On the basis of this information, we create a series of ordinal variables ranging from 0 to 2 and representing the policies adopted in the field of waste management. Specifically, the variable takes the value of 0 when the policy has not been adopted, 1 when the policy stringency is below the yearly median level, and 2 when it is above the median. After the creation of this indicator variable, we standardize the policy index by averaging all the policies adopted per country per year (hence, we averaged all the ordinal variables adopted per country per year). Table 1 summarizes descriptive statistics and data sources.

As a proxy for country specialisation in hazardous waste, we use a stock of knowledge measured by a patent stock. We retrieved information on patent applications at the European Patent Office in two different IPC classes that are related to the management of hazardous waste. These are:

- A62B 29/00 " Devices, e.g. installations, for rendering harmless or for keeping off harmful chemical agents";
- A62D 3/00 " Processes for making harmful chemical substances harmless, or less harmful, by effecting a chemical change in the substances".

EPO patent applications were assigned to the country of the applicant and the stock was built by means of the perpetual inventory methods (with depreciation 0.15). Moreover, to account for the general level of technology of countries, we also compute the total stock of EPO patents (depreciation rate 0.15).

Data about gravity variables (distance, contiguity, common language between partner and reporter) are taken from *CEPII* database[16]. These variables are considered as the specific determinants of bilateral trade flows between country pairs.

[15] Data are available here: http://www2.oecd.org/ecoinst/queries/. As these data only refer to countries that belong to the OECD, our sample only considers EU countries that also belong to the OECD.
[16] http://www.cepii.fr/cepii/en/bdd_modele/bdd.asp

Other covariates of our empirical analysis include:

- Total GDP, retrieved from the World Bank Development Indicator database;
- Population density, retrieved from the World Bank Development Indicator database;
- Installed capacity (in MW) of plants that recover energy from industrial waste, as a proxy of installed capacity of treatment plants, retrieved from Eurostat.

We began the analysis from the first year of application of the registry (2007) to 2014. The sample contains information about every region transaction outside the home country of hazardous waste in EU countries that also belong to the OECD.

Table 1-Descriptive statistics and data sources

	Mean	Stand. Dev.	Min	Max	Sources
Dependent Variables					
Export of HW waste	6792.894	44169.73	0	981537	*E-PRTR*
Count of transaction	5.727976	27.75168	0	444	*E-PRTR*
Total export (value)	6.05e+09	1.32e+10	486398	1.32e+11	*UN Comtrade*
Total export (weight)	3.64e+07	1.06e+08	500	1.77e+09	*UN Comtrade*
Independent Variables					
Gradient Population density	0	.9147465	-1.845704	1.845704	*World Bank*
Gradient Total patent stock (t-1)	0	1.587695	-2	2	*European Patent Office*
Gradient Patent stock in technologies for treatment of hazardous waste (t-1)	0	1.629107	-2	2	*European Patent Office*
Gradient policy stringency	0	1.149387	-2	2	*OECD*
Gradient MW capacity of energy recovery from hazardous waste	0	1.684172	-2	2	*Eurostat*
Gradient GDP	0	.6961583	-1.628009	1.628009	*World Bank*

log(distance)	6.956285	.6925747	4.087945	8.120583	*Cepii*
Contiguity	.1333333	.3399852	0	1	*Cepii*
Common language	.0238095	.152478	0	1	*Cepii*

4. Descriptive evidence

Figure 2 reports trends in the quantity of hazardous waste shipped as well as the trend in the number of transactions as reported in the E-PRTR. Between 2 million and 4 million of tonnes of hazardous waste were shipped every year in our selection of countries, with a fast growing trend. These shipments occur in about 2000-2500 transactions per year.

As visible in Figure 3, the ten most important bilateral flows over the whole period (accounting for 66 per cent of total shipments in our sample) are the export of waste from Italy to Germany and the export of waste from the Netherlands to Germany. This means that Germany represents the destination of the most important part of the whole European hazardous waste, suggesting the leadership of the Germany in this field. Figure 4, on the contrary, shows as the there is a correlation between the amount of waste produced by plants and their export propensity, although this relationship is not linear.[17]

Finally, in Figure 5 we report the patent stock at end of our period for selected technologies related to the management of hazardous waste, and compare it with the total patent stock. France emerges as the technological leader in terms of patents in the field of recovery and disposal of hazardous waste, followed by Germany and Italy. Interestingly, we observe that the ranking of countries when considering our selection of technologies does not overlap with the ranking for total patents, suggesting a pattern of specialization of certain countries in these technologies.

[17] The dots in figure represent the average value of shipment in each percentile of the shipment distribution.

Figure 2-Trend in hazardous waste shipments

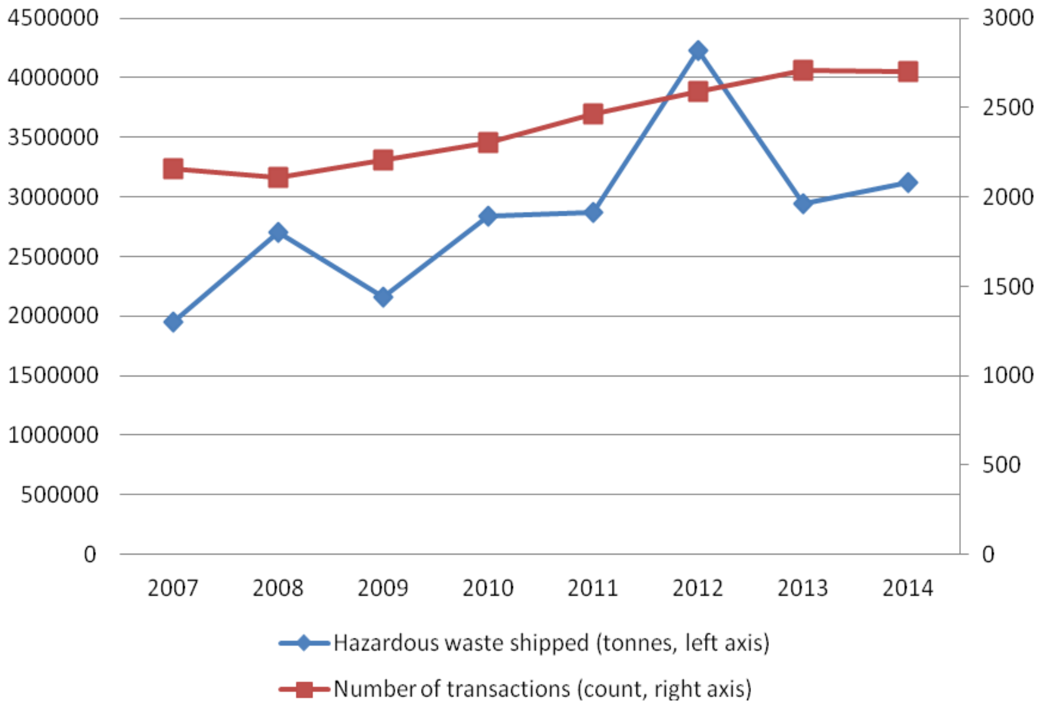


Figure 3-Relationship between total HW generation (percentile) and export propensity (share of exported Hw on total Hw)

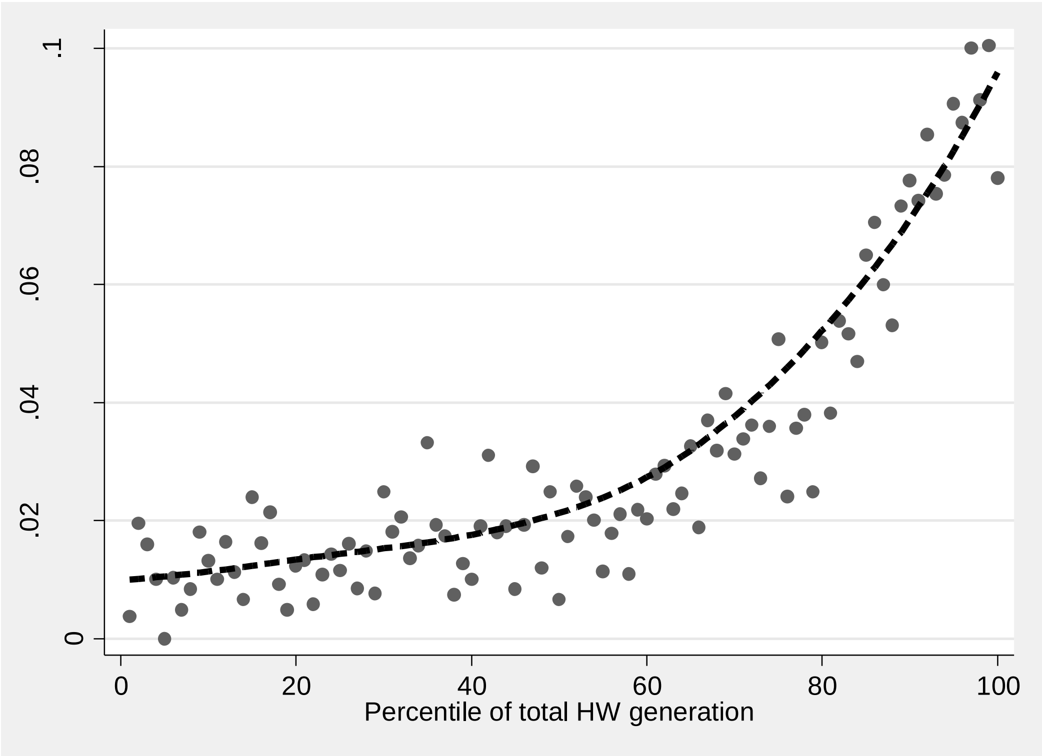


Figure 4- Most important bilateral flows

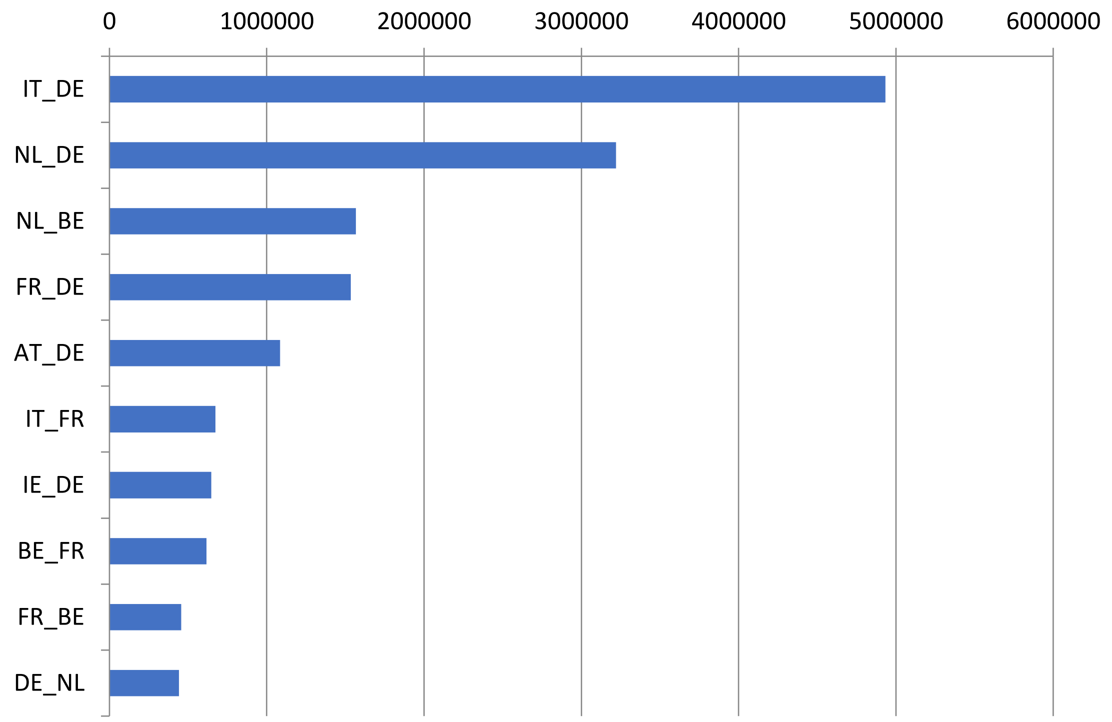
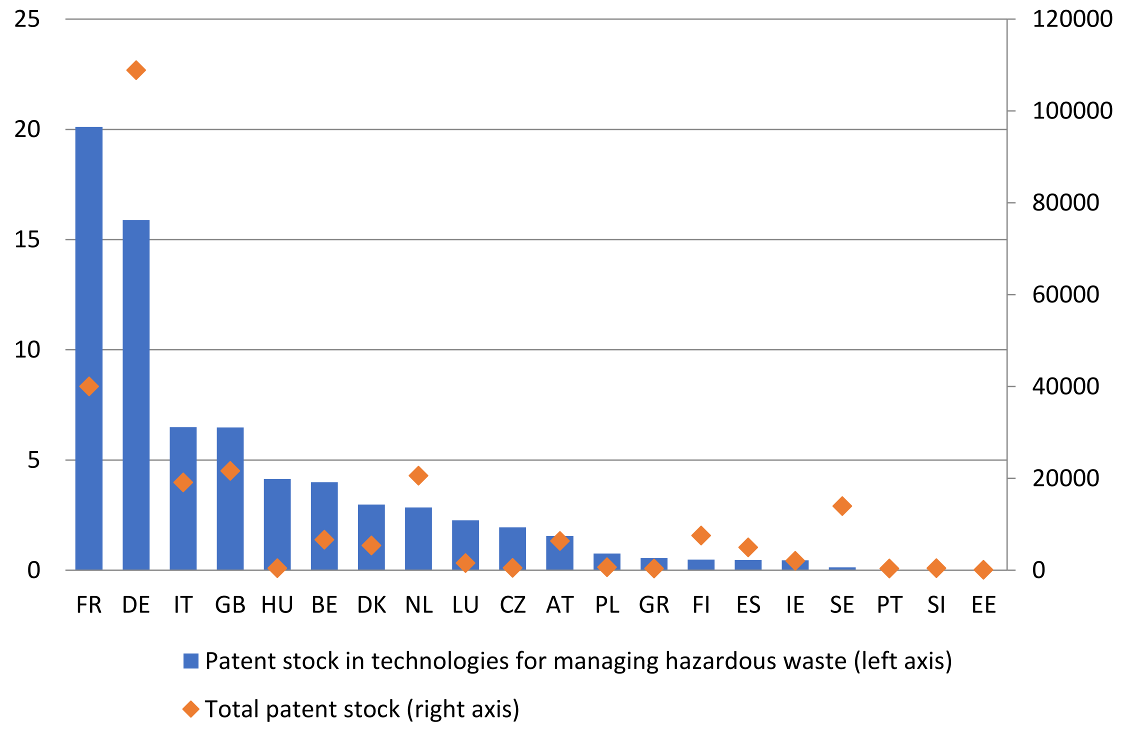


Figure 5-Stock of patent (2014) in relevant hazardous waste management technologies and total patent stock



5. Empirical model and results: Country analysis

We employ a gravity model to evaluate the drivers of shipment of hazardous waste across EU countries. The first theoretical explanation of a gravity model is given by Anderson (1979) and, ten years later, by Bergstrand (1989). They demonstrated that a gravity equation can be derived as a reduced form of many models of international trade. The gravity equation is a specification relating to nominal bilateral trade flows from exporter *i* to importer *j*. It is derived theoretically as a reduced form from a general equilibrium model of international trade in final goods. Exporter and importer GDPs can be interpreted in these models as the production and absorption capacities of the exporting and importing countries, respectively. Bilateral distance between the two countries is generally associated with transportation costs. We enrich this basic specification by accounting for the importance of drivers that are specific to the trade in hazardous waste. These variables relate to differences in regulatory stringency in the waste realm and differences in the technological endowment in the field of managing hazardous waste.

Following Kellenberg (2012), we express our variables in gradients using the midpoint formula. Specifically, these gradients follow this structure:

$$E_{ij}=(E_i-E_j)/((E_i+E_j)/2) \qquad (1)$$

where *i* and *j* represent the origin and destination country, respectively. Values larger than zero indicate that the origin country has a relatively larger value of the destination country. The advantage of this approach is having a comparison measure between two countries. For example, the gradient of patent stock represents the average percentage change in patent stock between importing and exporting country. If the destination country does not possess the essential technology to treat waste with respect to a potential exporter, then the gradient will be negative. The same is for the policy gradient, negative value implies that importing country has more stringent regulation. As visible from Table 1 in the Section above, the value of gradient variables in mean is equal to 0, because our gravity model is symmetric, so each pair and its reverse are cancelled. For the same reason the minimum and the maximum value are equal but with opposite sign. We estimate the following model:

$$WF_{ijt}=\beta_1 GDP_{ijt}+\beta_2 PS_{ijt}+\beta_3 WPS_{ijt}+\beta_4 ES_{ijt}+\beta_5 D_{ij}+\beta_6 L_{ij}+\beta_7 C_{ij}+\delta_{it}+\mu_{jt}+\varepsilon_{ijt} \qquad (2)$$

where:

- **WF**$_{ijt}$ is the export of hazardous waste between country pairs (in tonnes);
- **GDP**$_{ijt}$ is the gradient of the GDP between country pairs;
- **PS**$_{ijt}$ is the gradient of the total patent stock;
- **WPS**$_{ijt}$ is the gradient of the waste-specific patent stock;
- **ES**$_{ijt}$ is the gradient of our indicator of environmental policy stringency;
- **D**$_{ij}$ is the distance (in logarithm) between centroids of countries;
- **L**$_{ij}$ is a dummy that is equal to one if both countries share a common language;
- **C**$_{ij}$ is a dummy for common border between the two countries;
- δ_{it} and μ_{jt} are year-specific dummies for, respectively, reporter and partner countries.

In line with the recent literature, the model is estimated by means of the Pseudo Poisson Maximum Likelihood estimator (PPML) proposed by Santos Silva and Tenreyro (2006) to accommodate for the large share of zeros in gravity models. In fact, the transactions equal to zero in our dataset amount to 2.461 compared to 1.067 non-zero.

Table 2-Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
	Export of hazardous waste	Export of hazardous waste	Count of transactions	Export of hazardous waste	Total export (value)	Total export (weight)
Contiguity	0.178	0.191	0.534*	0.324	0.473***	1.044***
	(0.280)	(0.298)	(0.275)	(0.298)	(0.0765)	(0.122)
log(distance)	-1.463***	-1.483***	-1.610***	-1.444***	-0.503***	-0.778***
	(0.286)	(0.278)	(0.248)	(0.265)	(0.0552)	(0.0752)
Common language	1.356***	1.298***	0.833***	1.143***	0.755***	0.581***
	(0.245)	(0.228)	(0.224)	(0.235)	(0.108)	(0.146)
Gradient GDP	-0.326	-0.354	0.0692	-0.347	0.122	-0.0666
	(0.377)	(0.357)	(0.291)	(0.360)	(0.201)	(0.168)
Gradient Population density	-0.928	-0.636	1.409*	-0.610	0.214	0.832**
	(0.842)	(0.846)	(0.821)	(0.857)	(0.269)	(0.352)
Gradient Total patent stock (t-1)	-0.644***	-0.580**	0.168	-0.596**	0.0528	0.00736
	(0.217)	(0.234)	(0.202)	(0.234)	(0.0718)	(0.0811)
Gradient Patent stock in technologies for treatment of hazardous waste (t-1)	-0.353**	-0.503**	-0.540***	-0.500**	0.00315	0.0302
	(0.166)	(0.236)	(0.170)	(0.226)	(0.0531)	(0.0692)
Gradient policy stringency	0.672**	0.794*	0.770**	0.580	0.143	-0.0133
	(0.334)	(0.449)	(0.381)	(0.456)	(0.245)	(0.212)
Gradient MW capacity of energy recovery from hazardous waste				-0.280*		
				(0.147)		
Model	PPML	PPML	PPML	PPML	PPML	PPML

Year dummies	Yes	No	No	No	Yes	Yes
Origin country dummies	Yes	No	No	No	Yes	Yes
Destination country dummies	Yes	No	No	No	No	No
Year-specific origin country dummies	No	Yes	Yes	Yes	No	No
Year-specific destination country dummies	No	Yes	Yes	Yes	No	No
N	3360	2867	2867	2867	3360	3360

Standard errors clustered by reporter-partner pair in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Sample: AT, BE, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, NL, PL, PT, SE, SI and SK for 2007-2014.

Results reported in Table 2 provide confirmation to our hypothesis. In columns 1, 2 and 4 we evaluate the amount of shipments of hazardous waste (in weight) of bilateral shipments of hazardous waste while in columns 3 we consider the count of bilateral transactions between two countries. As a robustness check, we also evaluate total trade in value and weight (column 5 and 6, respectively) as a benchmark. Our expectation is that our waste-specific variables (mainly the waste-specific patent stock and the policy stringency indicator) have no influence on overall trade but only on trade of hazardous waste (Kellenberg, 2012).

With the only exception of column 1, where only origin, destination and year dummies are included, we include origin-year and destination-year dummies in all other regressions. Our first variable of interest, that is the (gradient of) proxy of stringency of waste-related regulation, features a generally positive and significant impact (columns 1, 2 and 3) on the quantity of hazardous waste that is shipped abroad. An increase of 10 percent in the relative stringency of waste-related environmental regulation in the origin country with respect to a potential destination country results in an increase in the export of hazardous waste (from origin to destination) of about 6.7-7.9 percent.

The gradient of the patent stock in technologies related to the management of hazardous waste has a negative impact on export of hazardous waste. If the origin country is particularly well endowed of appropriate technologies to deal with hazardous waste relative to a potential destination country, a lower amount of hazardous waste will be shipped to that destination country. A country's technological specialization is a factor influencing the patterns of international waste trade (see Baggs, 2009). It should be noted that this result is conditional on the overall differences in technologies across countries, that is accounted for by including the gradient of the total patent stock. This variable also has a negative impact on the export of waste. This suggests that the variable indicates the role of technological level between countries in general, and not only for the technologies about hazardous waste.

As a robustness check, in columns 4 we also include another proxy variable for the domestic availability of specific facilities to manage hazardous waste, that is gradient of installed capacity (in MW) of facilities for energy recovery of hazardous waste. This variable gives us information about the actual level of facilities in terms of efficiency in disposal/recycling waste. This variable turns out to be negatively related to the export of hazardous waste: if the destination country is relatively well endowed with of energy recovery facilities for hazardous waste (i.e. high gradient), producers in the country of origin will export hazardous waste to be used in these facilities abroad.

Results for total export (columns 5 and 6) suggest no influence of either policy stringency or waste-specific patent stock on trade patterns. This means that these variables do not pick up other unobserved factors that drive trade in general, but are specific to trade in waste.

Looking at our control variables, geography-related variables influence trade in the expected way, with distance being negatively related to waste shipments and presence of a common language showing a positive impact on trade. What is interesting here is that the elasticity of hazardous waste export with respect to distance is -1.5, much larger than the one estimated in gravity equations that look at total trade of standard commodities, that is estimated to be for the same sample of countries and period about -0.5 for the value of trade and -0.78 for the weight of trade (see columns 5 and 6 of Table 1). This result is not a surprise since the waste transport is very expensive compared to other standard commodities. Contiguity only matters for the extensive margin, that is the count of transaction and the probability of observing at least one transaction.

Relative differences in the size of the economy (total GDP) and in population density do not play any significant role in explaining the export of hazardous waste. Countries with relatively larger production of non-hazardous waste tend to export less hazardous waste while countries with larger production and domestic management of hazardous waste tend to export more.

An important concern regards the issue of endogeneity. Environmental policies can be influenced by firms. The biggest firms, playing an important role in their sector or even in the economy as a whole, could encourage policy makers to undertake particular environmental choices (Downing and White, 1986). Furthermore, if the environmental stringency (or absence thereof) is considered as a form of protection for industry, the import flows may be an important factor in environmental policy strategies. Similarly, the endogenous problem comes when we consider the technological variable. Successful technologies at time *t-1*, associated with positive import performances, could be a driver for future investments in research and development at time *t* in the same technologies. In this way the current patent stock could be influenced by the one of the past period. As Kellemberg (2012) argued, the use of environmental gradient can relax the issue related to the policy, in fact each country cannot introduce different environmental standards associated to each of countries partner. Furthermore, since the implementation of a specific treatment is not able to account for this question because of the absence of a counterfactual period, the use of year-specific origin and destination country dummies is a way to reduce these endogeneity concerns.

6. Regional analysis: data and results

Preserving the same literature and empirical context, we exploit the *microdata* provided by E-PRTR about origin and destination waste facilities. We consider the volume of hazardous waste shipped at NUTs 2 level between regions of OECD EU countries over the period 2007 to 2014. More specifically, in this case we study hazardous waste flows across plants, controlling for the role of some regional factors.

Figure 6- Volume of hazardous waste in OECD EU destination regions

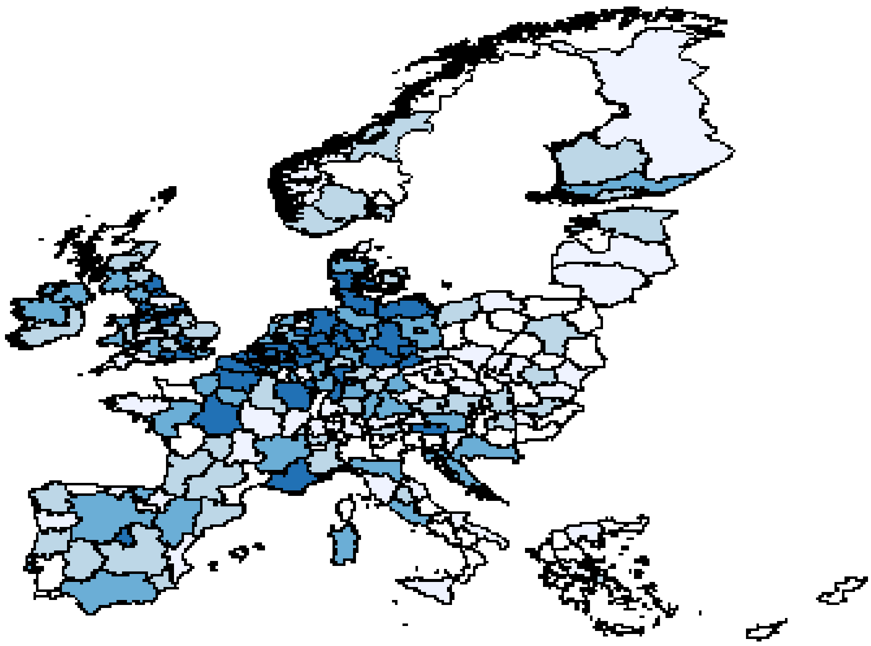


Figure 7- Relationship between number of exporting regions and total export of HW by plant

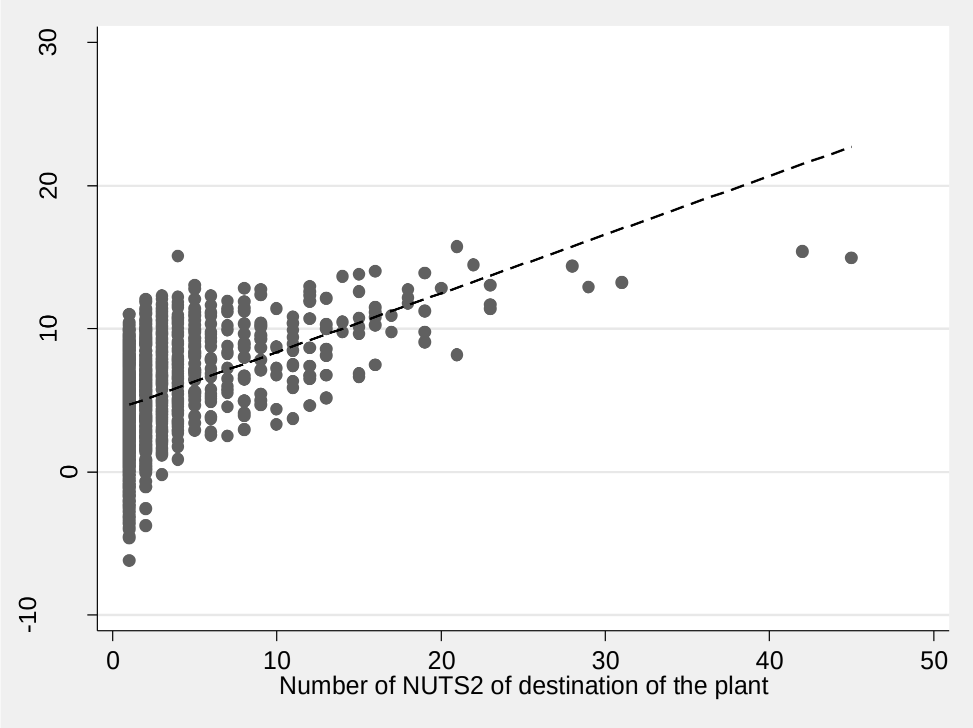


Table 3- Number of region associated to each exporting plant

Average 2.97
Median: 1 region
Maximum: 45 regions
50.7% only export to one region
68.4% to 1 or 2 regions
78.6% to 1, 2 or 3 regions

Figure 5 shows the investigated area and gives us an idea about the volume of hazardous waste exported in the destination regions. This is consistent with our expectation because most of volume of waste treated is concentrated in the central Europe, and in general in most developed EU countries[18]. Similarly, Table 3 above shows some light on the shipment structure. More specifically, it shows as, on average, every region exports to other three destination regions with a percentage of 78.6. Furthermore, exporting plants account for

[18] This is the case of Scandinavia, Germany, France and United Kingdom.

11.2% of total plants that generate hazardous waste, representing as much as 32.6% of total HW generation (either managed at home or exported) and these plants generate, on average, 3.9 times more hazardous waste than non-exporting plants. The average distance per tonne of waste shipped is around 496.5 Km (median 373.9 Km) while average distance per number of transactions is 649.1 Km (median 545.6).

Using the same estimated model discussed in the section 5,[19] we introduce some elements novelty. In particular as visible from Table 4, it can be argued that regional specialisation can influence waste flows. It is likely, in fact, that plants ship waste to destination plants or regions which are specialised in the specific type of waste that they produce.

Table 4- Waste sectors

Nace	Description	Number of exporting plants(share of tot)	Export of HW(share of tot)	Average export of HWper plant	Average number of destination NUTS2 per plant
01	Crop and animal production, hunting and related service activities	1.4%	0.0017%	37	1
05	Mining of coal and lignite	0.1%	0.0000%	7	3
06	Extraction of crude petroleum and natural gas	0.1%	0.0001%	44	1
07	Mining of metal ores	0.4%	0.0147%	1005	10.8
08	Other mining and quarrying	2.2%	0.0066%	90	2.2
09	Mining support service activities	0.1%	0.0017%	717	2
10	Manufacture of food products	5.0%	0.2358%	1422	2.1
11	Manufacture of beverages	0.6%	0.0331%	1698	6.8
13	Manufacture of textiles	0.3%	0.0013%	128	1.5
15	Manufacture of leather and related products	0.1%	0.0555%	22772	2
16	Manufacture of wood and of products of wood and cork	0.5%	0.0078%	457	5.6
17	Manufacture of paper and paper products	1.7%	0.0095%	169	2.1

[19] In this case *i* and *j* denote not countries but the region of export and the region of import, respectively.

18	Printing and reproduction of recorded media	0.5%	0.0154%	903	1.7
19	Manufacture of coke and refined petroleum products	2.4%	1.6361%	20327	2.9
20	Manufacture of chemicals and chemical products	16.4%	2.9937%	5554	2.1
21	Manufacture of basic pharmaceutical products	4.9%	7.0916%	44054	8.2
22	Manufacture of rubber and plastic products	1.7%	0.0599%	1068	2.7
23	Manufacture of other non-metallic mineral products	3.8%	1.3085%	10520	3
24	Manufacture of basic metals	11.1%	4.2583%	11639	1.8
25	Manufacture of fabricated metal products	11.0%	8.9035%	24500	1.5
26	Manufacture of computer, electronic and optical products	1.4%	0.2325%	5016	3.5
27	Manufacture of electrical equipment	1.5%	0.0540%	1107	2.5
28	Manufacture of machinery and equipment n.e.c.	1.0%	0.0224%	707	2.1
29	Manufacture of motor vehicles, trailers and semi-trailers	2.4%	0.0776%	964	1.9
30	Manufacture of other transport equipment	1.2%	0.0361%	924	1.3
31	Manufacture of furniture	0.1%	0.0013%	257	1.5
32	Other manufacturing	0.6%	0.2315%	11864	4.5
33	Repair and installation of machinery and equipment	0.5%	0.0055%	323	4.1
35	Electricity, gas, steam and air conditioning supply	4.4%	0.3834%	2664	3.3
37	Sewerage	1.0%	0.1722%	5433	0.9
38	Waste collection, treatment and disposal activities; materials recovery	19.1%	68.2927%	108430	3.6
39	Remediation activities and	0.3%	0.8490%	87018	2

	other waste management services				
42	Civil engineering	0.1%	0.0260%	5330	1
43	Specialised construction activities	0.1%	0.4144%	84951	1.5
46	Wholesale trade, except of motor vehicles and motorcycles	1.0%	0.0889%	2603	1.4
49	Land transport and transport via pipelines	0.2%	1.0015%	136876	4.3
52	Warehousing and support activities for transportation	0.3%	0.1597%	16369	1.5
72	Scientific research and development	0.1%	0.0001%	11	1.5
84	Public administration and defence; compulsory social security	0.1%	0.2203%	90310	7
	Total	100.0%	100.0%	30041	2.8

As a consequence, we built a specialization index for each destination region like a dummy variable equal to 1 if the destination region is specialized in the treatment or disposal of imported waste from the same activity sector of the exporting plant, and 0 otherwise. In fact, specialization S_d in destination regions is the ratio between:

$$S_d = EXP_{total} / EXP_{activity}$$

where EXP_{total} is the sum of total export by destination region and $EXP_{activity}$ is the sum of export by destination region sorted by activity. The variable is considered with a threshold of 20 percent, thus the variable takes value 1 if this ratio is greater than 0.2.

Similarly, we also control for the propensity to trade of different regions. The "internationalization index" is the simple gradient between the amount of hazardous waste exported in origin and destination regions, and it appears significant and with negative sign. In particular, the construction follows the gradient explained above:

$$Int = (EXP_{origin} - Exp_{destination})/((EXP_{origin} + Exp_{destination})/2)$$

Finally, we also control for the total amount of hazardous waste generated in the home region. Results are presented in Table 5. In order to make easier the discussion, the column 2 of Table

5 represents the *regional* gravity model with the same specification of the *macro* one (results reported in column 1), with the introduction of origin, destination and year dummies variable in both cases. Results seems to provide confirmation of our expectation also in the regional case, with only exception of the gradient of total patent stock, in this case is not significant. This result suggests that if the country's region has a particular technological advantage to deal with hazardous waste, a greater amount is shipped, despite the overall technological level. Furthermore, the *regional* model shows the importance of having a common border between regions, and underlines the role of distance. As in the previous model the distance is (negative) significant, so a greater distance between regions reveals a lower amount of waste flow. In the column 3 we control for the volume of hazardous waste treated domestically and we include proxy variables about regional specialization and internationalization.

An important role seems to be played by the specialization, because it reveals that, higher specialization in the treatment of particular categories of hazardous waste in the region, involves a greater amount of waste imported. This result is particularly relevant if we consider that in this specification the patents are not significant, therefore the presence of patents related to waste realm in general is important, but it is overtaken by being specialized in the disposal of a given category of waste treatment.

As expected, also the internalization index and the amount of hazardous waste produced in the home region shows a statistically significant coefficient associated with the expected sign.

Table 5- Baseline results

	(1)	(2)	(3)
	Export of hazardous waste	Export of hazardous waste regional (1)	Export of hazardous waste regional (2)
Contiguity	0.178	1.374***	1.269***
	(0.280)	(0.185)	(0.182)
log(distance)	-1.463***	-1.152***	-1.089***
	(0.286)	(0.0915)	(0.0748)
Common language	1.356***	-0.0949	-0.152
	(0.245)	(0.354)	(0.367)
Gradient GDP	-0.326	0.528**	0.383
	(0.377)	(0.251)	(0.253)
Gradient Population density	-0.928	-0.0160	1.0755
	(0.842)	(0.151)	(0.156)
Gradient Total patent stock (t-1)	-0.644***	0.0389	0.0174
	(0.217)	(0.0503)	(0.0586)
Gradient Patent stock in technologies for treatment of hazardous waste (t-1)	-0.353**	-0.0453***	-0.0115
	(0.166)	(0.0427)	(0.0548)
Gradient policy stringency	0.672**	0.630***	0.861***
	(0.334)	(0.239)	(0.282)
Total of HW generated and managed in home country			0.256***
			(0.0345)
Gradient internationalization			-0.0851***
			(0.0276)
Specialization in destination region			2.873***
			(0.244)
Model	PPML	PPML	PPML
Year dummies	Yes	Yes	Yes
Origin country dummies	Yes	Yes	Yes
Destination country dummies	Yes	Yes	Yes
N	3360	1387411	1387411

7. Conclusions and remarks

The aim of this paper is to consider the different drivers of international hazardous waste flows, in particular the relative levels of environmental policies, and technological specialization across countries and regions.

In line with previous literature, the presence of environmental policy shows a positive influence on the direction of hazardous waste shipments, confirming the role of more stringent regulation as a factor influencing the pattern of international trade. On the other hand, we find that also country specialization in treatments of hazardous waste matters. In fact, empirical evidences underline that countries with greater innovative technologies have a significant ability to deal with hazardous waste treatments (both recovery and disposal). As visible the results are confirmed at two different levels of analysis. *Regional* analysis conducted on regions at NUTs 2 level provides a confirmation and, introducing some elements of novelty, strengthens the results achieved through the country analysis.

However, we tried to mitigate the question of endogeneity using gradient variables and introducing dummies variables making the model as strong as possible, but we know that further researches are needed in order to assess the influence of endogeneity.

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How inequality and institutional setting impact on eco-innovation?

Abstract

This work tries to analyse the factors influencing the development of new eco-friendly innovations. We focused our attention on the role played by income distribution and government institutions, capable to foster the development of new technologies. Richest classes encourage the production of new technology through the demand of green goods. Furthermore, the presence of democratic and liberal societies brings good governance and builds states' capacity to promote economic and social development. Using environmental related patents as a good indicator of eco-innovation, we employed a count regression model combining these aspects in order to find the causal effect on generating eco-innovation.

1. Introduction

The development of new technologies represents an important issue especially in the environmental field. A growing body of literature analyses the generation of eco-innovations from different point of view, in particular the role of regulation capable of two main effect. On one hand regulation may induce a specialization process in eco-friendly goods or technologies, and on the other hand the possibility to relocate dirty production abroad, in particular in the poorest countries. In this context the literature underlines a large cross-variation among rich countries in environmental policy stringency and in the aptitude to develop green innovations. This allows to make way for uncertainty about the Kuznets curve hypothesis (Grossman and Kruger, 1995), according to which, above a given levels of income, economic growth leads to a significant reduction of emissions per capita levels. For this reason, seminal studies showed that this relationship holds in the case of local pollutants (Dinda, 2004)[20].

Furthermore, inequality within countries also impacts on the capacity of investing in green technologies. According to the literature (Beise and Rennings, 2005) different levels of income have two main contrasting effects. The first one is related to the economic growth cycle, that does not satisfy the necessity to generate appropriate environmental policy instruments and eco-innovation (Magnani, 2000). The second one concerns the consumption of eco-friendly product, that increases with income level. Therefore, it happens that high income inequality within country rises the demand of green goods (Heerink et al. 2001).

Seminal theoretical and empirical works argued that North-South income and institutional differences across countries can oppose to the reduction of the general level of environmental degradation (Chichilnisky, 1994; Chichilnisky and Heal, 1994). In this view a particular role seems to be played by the institutional context among countries. Democracies tend to be a driving force capable of influencing and facilitating scientific and technological innovation, but on the other hand non-democratic systems have a strong leadership able to foster innovation and technical improvements. Following a philosophy point of view liberal societies have a positive effect on innovation[21], as a result economic

[20] See also e.g. Harbaugh et al., 2004; Stern, 2004.
[21] This is the so-called Popper Hypothesis. See Popper (2005,2012).

literature underlines the possible link between democratic institutions and innovation performance (Salahodjaev, 2015), whereas Kuhn (2012) argued that institutional factors represent only a secondary aspect in the innovation process.

The purpose of this paper is to combine these two aspects. We want to extend the analysis on the relationship between income inequality and development of new green technology introducing the institutional setting. Using a count regression model this work tries to test the Popper Hypothesis and the role of income by examining the relative influence of these two aspects on the volume of environmental related patents.

The rest of the work is organized as follow. Section 2 connects the literature about inequality and institution framework to the environmental innovation. Section 3 presents data and empirical model. Section 4 is devoted to empirical results and possible extensions whereas Section 5 concludes.

2. Literature and framework

Innovation represents one of the most important driver of economic growth becoming increasingly especially in the last decades. Many studies underline the link between innovation and growth not only in developed countries, but also in developing ones that, through imitating process, foster domestic innovation (Zanello et. al, 2015). In this context a particular role is played by the social condition of each country in terms of political system of governments and income inequality.

According to the literature on democracy, recent works support the spillover effect of a democratic system that boosts social and economic development. Several studies suggested democratization like the primary objective in every developing country (Kohli, 1993; Leftwich, 1993) able to encourage innovation through the realization of focused developmental policies (Bottazzi and Peri, 2003; Nelson, 1993). Despite this branch of literature, some studies cast doubt on the positive impact of democracy on innovation conditioning this link on a combination of developmental background (Almond and Verba, 2015). In some sense they neglect the Popper Hypothesis giving to the democracy a marginal role. In a recent work Gao et al. (2017) tried to demonstrated the causality nexus between innovation performance and political structure studying the effect of some representative institutional variables on the number of inventions and patents considered a good indicator of technological development. In the paper they found no statistical significant evidence in favor of a democracy's effect on innovation, embracing the literature that neglect the Popper hypothesis.

H1: Democratic institutions influence the development of green technologies.

In order to study the link between democracy and innovation we test this hypothesis in the case of eco-innovation stressing its importance especially in the case of developing countries.

Another body of literature focused the attention on the relationship between inequality and technology development. Tselios (2011) showed that the existence of a richest social classes is essential to stimulate innovation activities.
This is especially relevant in the case of eco-innovation. Pioneer consumers have higher capacity to purchase green products more expensive than dirtiest ones, hence they trigger innovations. As a consequence, the price reduction allows also poorest consumers to buy this kind of products (Vona and Patriarca, 2011). Several studies showed that richest consumers have a greater environmental consciousness because of their higher education level, in this way the demand of green products rises.

H2: An unequal income distribution represents a stimulus to eco-innovation.

There are most relevant reasons to think that a great part of eco-friendly innovations arises from the demand of these new goods. First of all, as Murphy et al. (1989) showed, demand fosters the innovations characterized by high fixed cost, and this is the specific case of environmental innovation that require consistent investments.
This view is opposed because even in democratic societies the power decision is not equally distributed across individuals, but it reflects the income distribution. If the richest individuals are those who takes advantage from environmental degradation, more equal societies (where the power/income is more equal distributed) conduct to higher level of environmental protection (Boyce, 1994). Vona and Patriarca (2011) showed, thanks to empirical and theoretical arguments that, especially for richest countries, a more equal distribution of income induces the development of green goods and production processes.

3. Data and empirical model

3.1 Patents Application

Recent literature has exhibited great interest in studying technological innovation and the identification of good indicators has always represented a very relevant topic although there are very few instruments available. Many studies considered research and development expenditure like a good approximation of innovation (Magnani, 2000;), but in such a way R&D expenditure is an imperfect indicator of innovation performance since it represents only an *input* of research and development activities (Jonsthon et al., 2010).

Focusing on the *outputs* of innovation performance (i.e. the production of new technologies and new products), patents provide many useful information about invention and applicant. According to Griliches (1990) the use of patents is the best practice to debate about innovation topics, besides patents (sorted by year) are correlated to R&D expenditure, so they contain inside also information about the *inputs* of innovative activities.

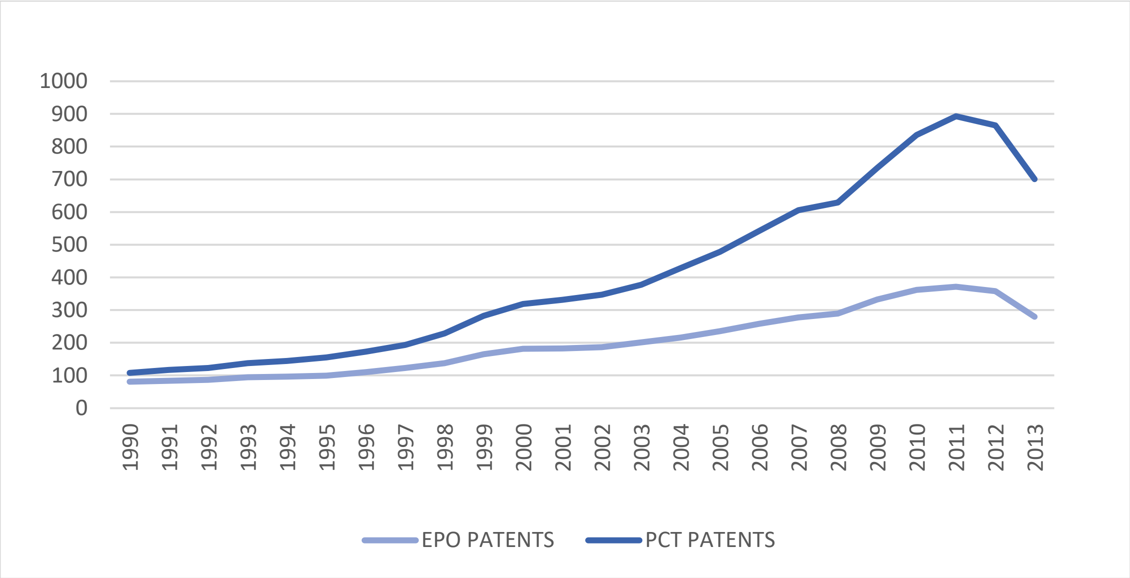
In order to study the impact of political institutions and income distribution on eco-innovation, we retrieved information about patenting in environmental related technologies from two different sources. The first one is The Patent Cooperation Treaty (PCT) that consents a strong protection in every contracting state by applying a single international patent application. The second one is the European Patent Office that offers patent's protection in 32 European member states. The EPO application is more expensive with respect a single application in national patent offices, for this reason EPO data ore most relevant because the higher price represents a sort of quality barrier eliminating low value applications (Johnston et al., 2010). It is important to emphasize that we consider the inventor's country that makes the application to EPO or PCT register. This is why we can consider countries that are not protected by either the EPO register or the PCT register.

Our analysis covers a long span of time and a large number of countries; in particular we build a panel dataset with 40 countries from 1990 to 2013 and it considers all OECD countries plus 5 developing countries[22]. Figure 1 reports trends in EPO and PCT patent applications (in mean) in environmental related technologies during the whole period. As

[22] BRICS countries, i.e. Brazil, Russia, India, China and South Africa.

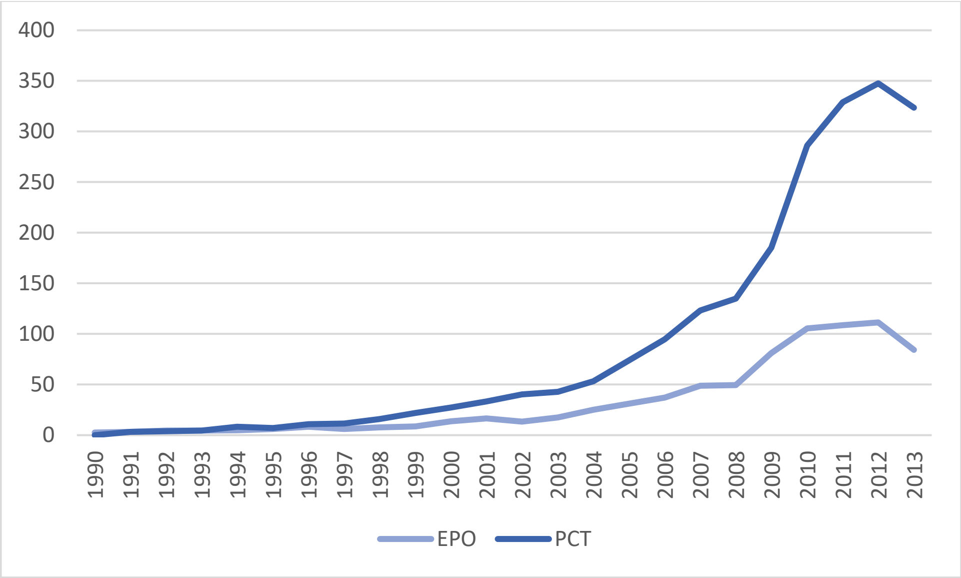
visible the development of eco-friendly technologies shows a strong growth in the last years of the period considered. Moreover, the average number of EPO patents is lower than PCTs.

Figure 8- Trends in EPO and PCT patent applications



The introduction of BRICS countries is particularly relevant in our analysis because it provides additional information especially in the case of environmental issues. Figure 2 reports the trend of patents application in BRICS countries in the period covered and it reflects the situation above, in fact also in developing countries the share of environmental patents is increased especially in 2012, in fact after a peak in 2012 they began to decrease in 2013.

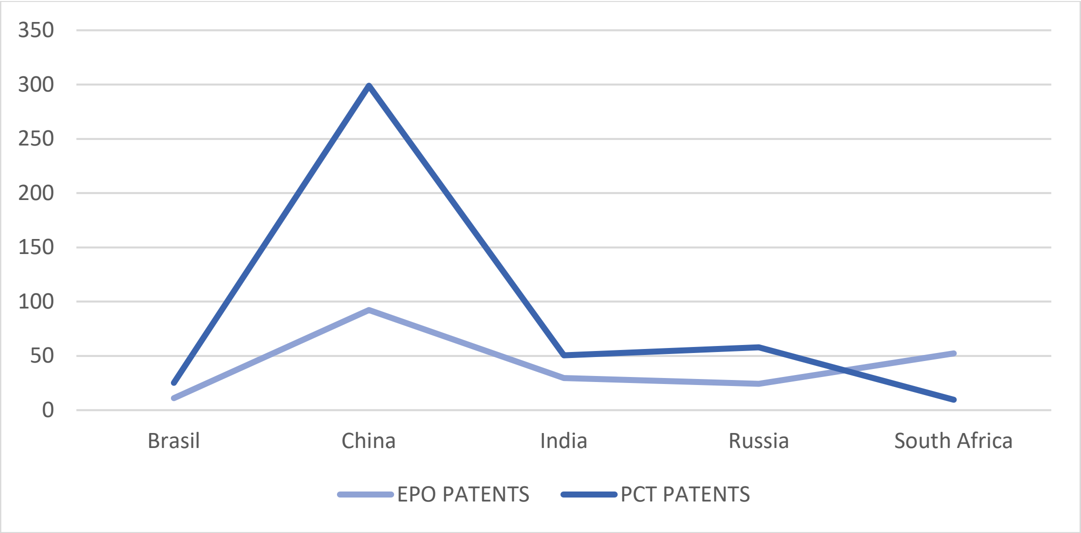
Figure 9- Trend EPO and PCT patents application BRICS countries



In particular Figure 3 shows that China[23] registers the leadership in environmental related innovation for both EPO and PCT applications, while Russia and India exhibit a quite similar share for both patents application. It is relevant to underline that the number of PCT applications is greater than the EPO ones in all cases with South Africa exception, probably this difference is due to the large number of PCT contracting countries and to the highest quality of EPOs.

[23] Values in mean considering the whole period covered.

Figure 10- Trends in EPO and PCT patent applications in BRICS countries



3.2 Explanatory variables

The aim of this work is to study the drivers of eco-innovation considering how the institutional setting and the distribution of income can affect the production of new technologies to decrease the level of environmental degradation as a whole. Table 1 summarizes the main statistics related to explanatory variables.

In order to account for income inequality, we considered in all specifications the Gini index. It is based on disposable income to account for differences across countries in fiscal policies and welfare regimes. The information about Gini are collected from The Standardized World Income Inequality Database (SWIID), that reflects the Gini coefficient at each percentile on the population which means that the Gini coefficient is given at lowest 1 percentile until top 100th percentile. In order to obtain a single Gini value per country per year we calculated the average of all the hundred Gini coefficients in the dataset.
We considered in the set of explanatory variables the GDP per capita per country per year, this information is taken from OECD.*Stat* database. Moreover, we decided to introduce the education level. The underlining idea of this choice is a positive correlation between years of study and the demand for low environmental impact products. For these reasons, the expectation is a positive effect of the education level on eco-innovation. We retrieved the information about educational level from the OECD.*Stat*.

Data about institutional systems are taken from different sources. Several indicators are used like a measure of the level of democracy of countries. We use the data of Polity2 index that are taken from Polity IV Project (Marshall et al., 2014). The Polity2 index takes values ranking from -10, when in the country there is a full autarchic political system, to 10 that corresponds full democracy.

Table 6- Descriptive statistics and data sources.

	Obs	Mean	Stand. Dev.	Max	Min	Fonte
GDP per capita	942	23856.42	13950.53	0	95352.29	*OECD*
Gini	956	32.34921	8.795913	0	59.65902	*SWIID*
Educ	597	27.09859	12.93387	4.757609	75.18226	*OECD*
Polity2	925	8.736216	2.9793	-7	10	*Polity IV Project*
Gov	946	40.36469	28.01064	1	83	*World Bank*

3.3 Model specification

In order to test the hypothesis set out in the Section 2 above, we present the following model:

$$\mathrm{PAT}_{it} = \beta_1 \mathrm{GINI}_{it} + \beta_2 \mathrm{GDP}_{it} + \beta_3 \mathrm{EDUC}_{it} + \beta_4 \mathrm{POLITY}_{\mathrm{it}} + \beta_5 \mathrm{TOTAL\ Pat}_{it} + \beta_6 \mathrm{GOV}_{it} + \alpha_i + \varepsilon_{it}$$

where i= 1, … ,40 indexes the cross-sectional unit (country) and t= 1990, …, 2013 indexes time. The dependent variable is measured by the number of patents in environmental related technologies and it is transformed as to assume integer values. The explanatory variables include:

- $GINI_{it}$ is the Gini index per country per year;
- GDP_{it} is the per capita GDP per country per year:
- $EDUC_{it}$ is the level of population that have reached a tertiary education level per country per year;
- $POLITY_{it}$ is POLITY2 index;

- GOV_{it} is the time length for which a country has had durable governments institutions;
- α_i are the fixed effect introduced to capture unobservable heterogeneity;
- ε_{it} is the error term that captures all the residual variation.

We used a negative binomial model in order to estimate our model. Count data models, such as the Poisson and negative binomial distribution, have been suggested for estimating the number of occurrences of an event (Wooldrige, 2002). In our case the number of patent applications at EPO and PCT represent a count variable because it is a realization of non-negative integer value. To this aim we supposed that the number of patents follows a negative binomial distribution. Moreover, we tried to estimate the model with a robust Poisson regression that is identical to a simple Poisson regression but with a robust estimate of the variance-covariance matrix.

4. Empirical results

Several alternative specifications of the model were estimated and Table 2 summarizes principle results. We repeated all specifications for both PCT and EPO patents in order to account for differences about the quality of inventions. Columns 1 and 2 provide results about the influence of income distribution on patent application. We confirm the positive role of GDP per capita, in fact the dimension of the economy has a great impact on the development of eco-innovations. Instead Gini index presents a positive e significant value, this result supports the pioneer consumers theory. In fact, the presence of the presence of an unequal distribution of income could lead to an increasing demand of green good that trigger the innovation reducing prices. Furthermore, this result provides a partial confirmation of our expectation about the role of education level. There is a positive and significant rule of education only in the case of PCT patents, this means that more educated population has a *push* effect in developing new green technologies.

Last two columns show the results of the full specification introducing institutional variables. As visible we can confirm the results provide in the first specification about GDP, Gini index and level of education. Focusing on the institutional setting we can prove the same results providing by Gao et al. (2017). It seems to be no effect of democracy institutions on eco-innovation. Although in column 4 the variable Polity2 is positive, it is not significant, while in the column 3 the variable Gov appears significant and with positive sign. This variable takes into account the government length and the hypothesis that a durable government can foster the generation of innovation through stable environmental policies and public investments. There is no doubt that policies and investments aimed at stimulating innovations require very long implementation time, this is the reason why this variable appears significant and with expected sign. As is visible, the number of observation decrease across estimations, in non-linear models the fixed effects are conditioned out of the likelihood which is then maximized. The main point regarding is that conditional likelihood estimators can only use observations for which the outcome varies. If there is only one observation in the group, then there is no within variation with uninformative result.

Table 7- Baseline results

	(1)	(2)	(3)	(4)
	Pat_PCT	Pat_EPO	Pat_PCT	Pat_EPO
GDP per capita (log)	1.669***	1.597***	1.558***	1.456***
	(0.120)	(0.113)	(0.134)	(0.137)
Gini	0.009***	0.008**	0.010***	0.008**
	(0.003)	(0.003)	(0.003)	(0.003)
Educ	0.029***	0.008	0.022***	0.005
	(0.005)	(0.005)	(0.006)	(0.006)
Polity2			-0.050	0.014
			(0.040)	(0.039)
Gov			0.009**	0.007
			(0.004)	(0.004)
Total PCT	.0000172 ***		.0000161 ***	
	(0.000)		(0.000)	
Total EPO		.0000167 ***		.0000155 ***
		(0.000)		(0.000)
Observations	594	594	582	582
Log likelihood	-2268.563	-2235.640	-2252.023	-2215.562
Prob>Chi2	0	0	0	0

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8- Baseline results no BRICS

	(1)	(2)	(3)	(4)
	Pat PCT	Pat EPO	Pat PCT	Pat EPO
GDP per capita (log)	1.669***	1.602***	1.558***	1.461***
	(0.121)	(0.113)	(0.135)	(0.137)
Gini	0.009***	0.007**	0.009***	0.008**
	(0.003)	(0.003)	(0.003)	(0.003)
Educ	0.029***	0.008	0.022***	0.004
	(0.005)	(0.005)	(0.006)	(0.006)
Polity2			-0.046	0.015
			(0.041)	(0.040)
Gov			0.009**	0.007
			(0.004)	(0.004)
Total_PCT	.0000172 ***		.000016 ***	
	(0.000)		(0.000)	
Total_EPO		.0000166 ***		.0000155 ***
		(0.000)		(0.000)
Observations	581	581	569	569
Log likelihood	-2227.7163	-2202.9183	-2211.2834	-2182.863
Prob>Chi2	0	0	0	0

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Sample without BRICS countries

We tried to estimate our model eliminating BRICS countries. The results are reported in the Table 3. The structure of the model is the same of the previous one. Despite the absence of BRICS countries, that represents a great part of eco-innovation activity in the last years, the results hold with respect the full dataset.

We can confirm the role of GDP and the positive effect of Gini index, the same is for the tertiary level of education. It would seem that the size of the economy is one of the factors determining the development of new technologies, combined with the presence of a large gap in income distribution. It would appear that the increase in GDP leads to an increased demand for green technologies. This seems consistent with the literature, with the growth of the economy environmental degradation decreases. Institutional variables are not significant except the one about the length of government and this result is very relevant for our analysis. Brics countries present very particularly governments, for example China has the leadership in innovative technologies with high growth rates, but in the same time the power is exercised by the only Chinese Communist Party. In general, the government structure of Brics countries is distant of being liberal with respect OECD countries present in our dataset.

4.1 Robustness Check

As a robustness check, we tried to estimate the model using a fixed effect Poisson model with robust standard errors, that according to Wooldrige (1999) tends to be more reliable, although it is unlikely to be efficient.

Table 9- Poisson model with robust standard errors

	(1)	(2)	(3)	(4)
	Pat PCT	Pat EPO	Pat PCT	Pat EPO
GDP per capita (log)	1.556***	0.970***	1.111**	1.008**
	(0.327)	(0.340)	(0.539)	(0.459)
Gini	0.008***	0.010***	0.008***	0.010***
	(0.003)	(0.002)	(0.003)	(0.001)
Educ	0.048***	0.041***	0.041*	0.041***
	(0.018)	(0.013)	(0.022)	(0.016)
Polity2			0.119	0.091
			(0.124)	(0.126)
Gov			0.022	-0.001
			(0.024)	(0.018)
Total PCT	0.0000162		0.0000145	
	(0.0000103)		(0.00000950)	
Total EPO		0.0000129		0.0000129
		(0.0000161)		(0.0000164)
Observations	594	594	582	582
Log likelihood	-4859.8602	-3860.3859	-4797.3265	-3828.4585
Prob>Chi2	0	0	0	0

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

The first set of estimations reported in Table 4 confirmed our hypothesis and previous results. GDP per capita has a positive and significant effect on both applications, the same is for the Gini Index and for the role played by education level, that appears significant in every specifications meaning the strong impact have the educational level as driver of eco-innovation. In these specifications the count of total patents seems to be significant, unlike what happened before. Looking at institutional setting we find interesting results in this specification. As visible, democratic institutions seem to have no role in fostering green patents. To this aim our results seem to embrace the literature that rejects Popper's hypothesis discussed above. It is only the income distribution that has an effect and these empirical results appear to confirm our expectation in *H2*. The relationship between inequalities and green innovation appears very strong in every specification suggesting the proactive role of inequality in fostering green innovation.

In order to check the role played by Brics countries, we estimate the same model without them as above. Results are reported in Table 5. This estimation confirmed the previous results. Despite the absence of developing countries we can confirm hypothesis two and neglect the first one.

Table 5- Poisson model with robust standard errors no Brics

	(1)	(2)	(3)	(4)
	Pat PCT	Pat EPO	Pat PCT	Pat EPO
GDP per capita (log)	1.559***	0.972***	1.114**	1.009**
	(0.328)	(0.341)	(0.540)	(0.459)
Gini	0.008***	0.010***	0.008***	0.010***
	(0.003)	(0.002)	(0.003)	(0.001)
Educ	0.047***	0.041***	0.041*	0.041***
	(0.018)	(0.013)	(0.022)	(0.016)
Polity2			0.119	0.091
			(0.124)	(0.126)
Gov			0.022	-0.001
			(0.024)	(0.018)
Total PCT	.0000161		.0000144	
	(.0000103)		(9.50e-06)	
Total EPO		.0000129		.0000128
		(.0000161)		(.0000164)
Observations	581	581	569	569
Log likelihood	-4817.081	-3822.0645	-4754.677	-3790.141
Prob>Chi2	0	0	0	0

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Sample without BRICS countries

5. Conclusions and remarks

In this research we investigated the causal effect that income distribution and institutional system have on the generation of eco-friendly innovations. Our analysis shows a significant role of fabric of society. High income social classes usually present high education level and therefore a stronger environmental awareness that drives them to ask for more expensive green goods. Hence, thanks to an imitating process, clean goods become more accessible even for less well-off social classes. In this way rich class, pushing the demand, fosters eco-innovation.

Furthermore, the results seem to neglect Popper Hypothesis. In the first specification the length of government exhibits a relevant effect, but this variable itself is not a sign of democracy or not. This would only demonstrate that the innovative process requires stability despite the form of government.

Second specification confirm our results. However, this does not mean that there is clear evidence. The Polity2 index, which measures the degree of democracy of a society, while being positive (more democracy and more innovation), never becomes significant. Governments in autocratic countries decide to invest more resources in science and technology research to increase their power (as is the case of Russia and China). On the other hand, democratic countries are much more open in every aspect. Even if they are not at the cutting edge of innovation, democratic countries can more easily receive technology transfers from countries with similar regimes (Allison, 2002). Democratic countries can import advanced technologies from abroad rather than prioritizing domestic innovation. This appears an efficient path to economic growth in the age of globalization[24].

[24] For a complete literature about trade liberalization and environment see the first essay of this work.

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