Environmental Regulation and the Export Dynamics of Energy Technologies

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NOTA DI LAVORO 53.2007

MAY 2007

CCMP – Climate Change Modelling and Policy

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Summary

The pollution haven hypothesis affirms that an open market regime will encourage the flow of low technology polluting industries toward developing countries, due to potential comparative advantages related to low environmental standards. In contrast, the hypothesis suggested by Porter and van der Linde claims for a competitive dynamic behaviour by innovating firms, allowing a global diffusion of environmental-friendly technologies. Environmental regulation may represent a relevant mechanism through which technological change is induced. In this way countries subject to more stringent environmental regulations may become net exporters of environmental technologies. This paper provides new evidence on the evolution of export flows of environmental technologies across different countries for the energy sector. Advanced economies, particularly the European Union, have given increasing attention to the role of energy policies as tools for sustaining the development path. The Kyoto Protocol commitments, together with growing import dependence of energy products, have stimulated the attention on the analysis of innovation processes in this specific sector. The analysis uses a gravity model in order to test the determinants and the transmission channels through which environmental technologies for renewable energies and energy efficiency are exported to advanced and developing countries. Our results are consistent with the existence of the Porter and van der Linde hypothesis, where environmental regulation represents a significant component of comparative advantages. What strongly emerges is that the stringency of environmental regulation supplemented by the strength of National Innovation System is a crucial driver of export performance in the field of energy technologies.

Keywords: Environmental Regulation, Trade and Environment, Energy Technologies

JEL Classification: F18, F21, Q43, Q55, Q56

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1. INTROUCTION

The interaction between trade flows and environmental regulations has become quite a topical issue recently. There is a common belief that by applying more lenient environmental regulations, countries tend to reduce production costs of their manufactures and thus improve their ability to export, despite the possibility to become pollution havens. There have been many empirical studies performed in this field, trying to estimate this relationship. Empirical results provide non univocal results supporting this relationship (Antweiler *et al*., 2001; Bommer, 1999; Copeland and Taylor, 2003; Grether and De Melo, 2003; Letchumanan and Kodama, 2000, Levinson and Taylor, 2004, among the others). On the contrary, the theory of dynamic competitiveness deriving from technological innovation linked to stringent environmental standards has been exposed fashionably by Porter and van der Linde (1995). Even in the case of this second hypothesis results are not univocal, and many additional conditions, rather than only stringency of environmental regulations, provide comparative advantages obtained through technological leadership. These additional conditions include a number of factors, such as the existence of an international framework in which environmental standards are homogeneous, the existence of a long-term perspective, thus reducing investment risks, but above all the possibility to obtain high profit margins from being first comers.

Looking at recent documents published by the European Commission, it seems that the Kyoto Protocol could be an efficient framework of environmental regulation, with an international institutional framework which could reduce uncertainty, increase market demand for environmental-friendly products and technologies, and increase profit incentives for first comers. The existence of the flexible mechanisms in the Kyoto Protocol provides the institutional framework for the functioning of a regulated market where virtuous firms can sell their clean products. At the same time, the necessity to substantially reduce Greenhouse gases (GHG) emissions with domestic measures seems to push towards increasing technical progress within the Annex I countries. In this specific case, there is no complete agreement at international levels about the real costs for industrialized countries related to climate change control policies. Following the position of the United States, the economic impact for domestic firms could be negative, with increasing production costs and loosing international competitive advantages.

On the contrary, the European Union has fully embraced climate change as a global problem where industrialized countries could be the first engine for the development of clean technologies. Considering the EU long-term development strategies, i.e. the Lisbon strategy and the Goteborg Declaration, the EU considers technical progress as a major source of dynamic growth, and environmental regulations can be interpreted as a positive impulse to economic development. Rather than continuing with carbon intensive production processes and products, the European firms should adopt an innovation path oriented towards renewable energies and energy efficiency.

The institutional framework of the Kyoto Protocol in this last years is highly supported by other contingent and structural factors, such as the increasing oil price on the international markets and the increasing concerns for security of energy supply, respectively. For instance, the increasing availability of renewable energies could be a positive factor for industries even without considering the energetic constraints linked to the Kyoto Protocol.

Following this line of reasoning, the availability of renewable energies and energy saving technologies could be a source of cost savings even for developing countries, actually without any bound on GHG emissions, but with high energy costs due to increasing demand for fossil fuels, necessary to sustain fast economic growth processes. This could be the case of emerging countries, in particular Brazil, China and India, where fossil fuels consumption is increasing much more than the increase in fossil fuels production at global level. The reduction of dependence from fossil fuels is strictly linked with reducing pressure on countries (Middle East and African countries above all) that are typically characterized by political instability. The diversification of the energy mix is functional to the reduction of risks and uncertainties, thus reducing long-term costs for firms with energy-intensive production processes.

In this paper we will try to shed some light on this possible virtuous cycle between environmental regulations, increasing competitiveness and technology diffusion analyzing a very specific industrial sector, such as technologies for the production of renewable energies and energy saving. The choice of such a specific focus, and the possibility to test validity of the Porter and van der Linde hypothesis, allows us to understand if the Kyoto Protocol can be really an efficient environmental regulation framework. The empirical model used in this context is based on a gravity equation for international trade flows, following many other empirical studies focusing on the effects of environmental regulation on trade flows.

The rest of the paper is structured as follows: Section 2 gives a brief overview of alternative models analyzing the relationships between environmental regulation, innovation and trade; Section 3 gives some details of empirical models using gravity equations; Section 4 describes the dataset and the methodology used, while in Section 5 the main empirical results are reported, and Section 6 concludes with some policy implications.

2. ENVIRONMENTAL REGULATION, INNOVATION AND TRADE

The introduction of more stringent environmental regulations has been traditionally seen as potentially harmful for the productivity and competitiveness of the national industry as it leads to higher costs faced by firms. During the last decade, in a context of increasing flows of international trade, this issue has been largely debated. It has been claimed that by applying more lenient environmental regulations, countries tend to reduce production costs of their manufacturers, improving their international competitiveness, but also, potentially becoming what the literature calls "pollution havens" (Copeland and Taylor, 2003).

However, even if at a first sight, the performance of the economy in which more stringent environmental policies are implemented seems to be definitely harmed, it can be argued that flows of innovation induced by the introduction of severe environmental regulations allow a country to become a net exporter of environmental technologies. In fact, the international spread of regulatory innovations can be accompanied by an expansion of markets for environmental protection technologies. The country that firstly introduced more stringent environmental standards, by increasing the pressure on industry to develop environmentally compatible production processes, can gain consistent advantages in the market for these technologies or environmentally friendly products. The argument, in its most strong formulation, is that the shock produced by a new regulation creates an external pressure on firms, which are fostered to create new products and processes, that positively affect the dynamic behaviour of that economy and hence its competitiveness and the overall social welfare (Porter and van der Linde, 1995). According to Jaffe *et al.* (1995), a weak interpretation of the hypothesis brings to a win-win situation where the stringent environmental regulation will increase private net benefits of firms.

These two contrasting views – the pollution haven effects and the Porter hypothesis - have been subject to a substantial amount of empirical analyses which, however, remained largely inconclusive. On the one hand, most of the empirical studies estimating the existence of a pollution haven hypothesis do not succeed in finding robust support for this argument (Harris *et al.*, 2002; Jug and Mirza, 2005). Other studies using specific data for the United States find a significant effect of stringency on net imports adopting an endogenously determined environmental stringency variable (Ederington and Minier, 2003; Levinson and Taylor, 2004).

However, these results at least cast some doubts on the effective relevance of the Porter hypothesis in its broader formulation. The latter implies that the benefits related to the generation and the diffusion of new technological knowledge, induced by the introduction of more stringent environmental regulation, produce relevant spill-over effects in the whole economic system spurring its productivity and its comparative advantages. Moreover, also the extensive empirical research on the relationship between regulation and green innovation failed to produce clear evidence on the subject also due to poor indicators of both regulation and environmental innovations (Jaffe *et al*., 1995, 2005; Jaffe and Palmer, 1997).

The aim of our analysis is to restrict the attention on a specific type of environmental-friendly technologies rather than testing the effects of regulation on the generic trade flow. What we try to find out here is that the introduction of more severe environmental regulations spurs a country's ability to export those technologies abroad. If this research hypothesis is confirmed, the empirical results can shed some lights on the effectiveness of some of the mechanisms underlining the Porter hypothesis that much of the previous literature failed to properly address.

In order to build our empirical investigation we have looked at a narrow set of environmental technologies considering only the energy sector, such as the production of renewable energies and energy saving processes and products. Focusing the attention on this specific sub-set of environmental technologies, we have considered the fact that environmental protection includes a number of different activities, involving both private and public goods. It is the nature itself of the specific environmental good which conduces towards a multiple set of policy actions, whose efficacy is highly dependent on the chosen mechanism (standards, taxation, market mechanisms, etc.).

Considering the energy sector, we have made implicit considerations about the role of the Kyoto Protocol as an institutional framework formulated in order to reduce typical problems affecting environmental regulation. The Multilateral Environmental Agreements typically reduce the existence of free-riders, thus guaranteeing an equal distribution of benefits and costs. Moreover, the Kyoto Protocol provides an institutional framework particularly favourable to technology diffusion, where market instruments are implemented (the flexible mechanisms) with the specific aim of reducing costs for private industries and promoting the diffusion of environmental-friendly technologies, especially in developing countries.

Looking at specific requirements for efficient environmental regulation highlighted by Porter and van der Linde (1995), the Kyoto Protocol seems to be well designed because: 1) its focus is on outcomes and not technologies (it has clear goals but a flexible approach); 2) it allows an extended use of market incentives (including tradable permits); 3) it is based on an extended regulatory coordination (between industries and regulators, as well as among many international counterparts). Such a specific focus clearly help reducing the influence of an inefficient environmental regulation on the empirical results of a possible Porter hypothesis, which clearly specifies the positive influence of “properly designed environmental standards” on the paradigm of dynamic competitiveness (Porter and van der Linde, 1995, pp. 98). As underlined in Wagner (2003), an inefficient regulation increases compliance costs for firms, thus making it less likely for innovation benefits to offsets costs, thus introducing a systematic bias in empirical studies.

3. REVIEW OF EMPIRICAL MODELS USING GRAVITY EQUATIONS

Many empirical investigations addressing the relationships between environmental regulation and trade flows have adopted a gravity equation model.

Probably the gravity equation is the most successful empirical trade devise of the last forty years. Applied to a wide variety of goods and factors moving over regional and national borders under different circumstances, it usually produces good fit.

The model was first used by Tinbergen (1962), and the basic theoretical model for trade between two countries (*i* and *j*) takes the form of:

$$F_{ij} = G\frac{M_i^{\alpha} M_j^{\beta}}{D_{ij}^{\theta}} \qquad [1]$$

The formulation by Tinbergen (1962) applied to international trade is quite the same functional form of the “Law of Universal Gravitation” developed by Newton in 1687. The exact notation is defined as follows: F_{ij} is the flow from origin i to destination j, M_i and M_j are the relevant economic sizes of the two locations, measured as the gross domestic product (GDP) and/or as the population of the two locations. D_{ij} is the distance between the locations (usually measured centre to centre). G is a gravitational constant depending on the units of measurement for F_{ij}, M_i and M_j.

The gravity equation can be thought of as a kind of short-hand representation of supply and demand forces. If country i is the origin, then M_i represents the total amount it is willing to supply to all customers. Meanwhile M_j represents the total amount destination j demands.

Distance acts as a counter force, where the larger the distance the higher the trade and transport costs.

The gravity equation of trade predicts that the volume of bilateral trade is positively related to the product of the countries' GDP and negatively related to trade barriers between trade partners (Leamer and Levinson, 1992).

A large body of literature try to understand both theoretically and empirically the real explanation capacity of the gravity model for increasing trade flows, including the investigation of other conditional variables such as the role of trade openness (or protectionism), and other policy aspects, such as environmental regulation.

Following Anderson (1979), it has been increasingly recognized that the gravity equation prediction can be derived from very different structural models, including Ricardian models, Heckscher-Ohlin models, and increasing returns to scale models (IRS).

As underlined in Evenett and Keller (1998), when consumers have both identical homothetic preferences and access to the same goods prices, a sufficient condition for obtaining a gravity equation is perfect product specialization (each commodity is produced only in one country). The three types of trade models differ in the way product specialization is obtained in equilibrium: technology differences across countries (in the Ricardian model), factor proportions (in the H-O model), and increasing returns at the firm level in the IRS model.

As suggested by Hummels and Levinsohn (1995), something other than IRS is responsible for the empirical success of the gravity equations.

In a constant returns H-O world, bilateral factor proportions differences must be very large in order to ensure that the economies lie outside a common space of diversification and to generate product specialization. Therefore, in the H-O model, trade is mainly (exclusively) inter-industry trade, explaining the North-South trade. For the IRS model at least some, potentially all, trade is intra-industry trade, explaining the North-North or the South-South trade patterns (Evenett and Keller, 1998). This might suggest that the gravity equation could be used both for explaining trade flows between countries with large factor proportion differences and for trade partners with high shares of bilateral intra-industry trade.

In order to facilitate empirical computation of the gravity model, eq. [1] can be transformed in log terms, hence obtaining a linear relationship as follows:

$$\ln F_{ij} = \ln G + \alpha \ln M_i + \beta \ln M_j - \theta \ln D_{ij} + \varepsilon_{ij} \qquad [2]$$

The value of ln*G* (a constant term) corresponds to the intercept, while the expected value of the coefficient α and β is not significantly different from 1. The inclusion of the error term ε_{ij} delivers an equation that can be estimated using econometric techniques.

The empirical model often includes variables to account for other aspects than GDP and population, such as price levels, language relationships, tariffs, spatial contiguity, and colonial history.

The following major explanations try to highlight the importance of distance in trade flows: (i) distance is a proxy for transport costs; (ii) distance indicates the time elapsed during shipment, and this is mainly an important aspect of trade for perishable goods; (iii) distance is important for the synchronization of multiple inputs in the production process; (iv) communication and transaction costs increase with distance.

The gravity equation has been widely used to analyse the relationship between environmental regulation and trade flows, especially in a research context oriented towards the investigation of the existence of a pollution haven effect. Recent examples of such analyses are Greter and de Melo (2003), Harris *et al.* (2002), Jug and Mirza (2005), van Beers and van den Bergh (2000), all addressing for the existence of a pollution haven path of trade flows related to more stringent environmental regulation. The results are not univocal, thus not producing robust findings in favour of the pollution haven effects. Nonetheless, many interesting results have been produced especially related to the modelling of the variables explaining environmental regulation stringency.

On the other side, empirical findings of the Porter hypothesis are mainly based on specific industries rather than a broad sector or economic system, because it is necessary to identify more precisely conditions and parameters for an industry to profit from stringent regulation (Wagner, 2003). In this sense, Albrecht (1998) has focused his analysis on specific industries affected by the Montreal Protocol on Ozone-Depleting Substances (e.g., refrigerators, freezers, air conditioning equipments, etc.), and he provides evidence on the Porter hypothesis for two countries, Denmark and the United States. The choice of an international regulatory framework such as the Montreal Protocol is in line with the reduction of biases related to inefficient environmental standards. In the same venue, Murty and Kumar (2003) analyse the influence of environmental regulation on the productive efficiency of specific firms in water-polluting industries in India, finding that the higher is firms' compliance, the lower is the technical inefficiency of the firm, thus lending support to the Porter hypothesis.

Finally, from the meta-regression analysis provided by Mulatu *et al.* (2001), there emerges that econometric studies based on gravity equation models seem to provide less evidence in favour of the pollution haven hypothesis, thus indirectly supporting the Porter hypothesis.

4. EMPIRICAL MODEL AND DATASET

The empirical formulation of the gravity equation used in this paper is quite similar in the formal structure to other gravity equations used for the analysis of the impact on trade flows related to environmental stringency.

The exporting countries for this analysis (our *i* countries in the gravity equation) are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States. The sample for *j* countries includes 148 countries (including OECD countries). The time period analyzed goes from 1996 to 2005 (unfortunately in most of the countries there are data only until 2004).

The exact formulation of the gravity equation analyzed in a panel context is as follows:

$$\ln EXP_{ijt} = \alpha + \beta_1 \ln \mathbf{M}_{it} + \beta_2 \ln \mathbf{M}_{jt} + \beta_3 \ln \mathbf{G}_{ij} + \beta_4 \mathbf{E}_{it} + \beta_5 \mathbf{E}_{jt} + \\ + \beta_6 \mathbf{I}_{it} + \beta_7 \mathbf{I}_{jt} + \beta_8 \mathbf{X}_{jt} + \varepsilon_{ij} \qquad [3]$$

The dependent variable EXP_{ijt} represents the bilateral export flows (from country *i* to country *j*) at time *t* of technologies for renewable energies and energy saving (calculated at 2000 constant PPP international $). Data for export flows are extracted from COMTRADE database (UNCTAD) based on the Harmonized Commodity Description and Coding System (HS 1996). The typologies of technologies to exploit renewable energies and to enhance energy efficiency are well defined by OECD (Steenblick, 2005) starting from the classification HS 1996 (see Appendix Table A2). In the OECD document the list includes all processes and products with the principal purpose of environmental protection. In this paper we have restricted the sample covering only technologies for the energy sector. This methodological choice strictly derived from the general framework of this study, where we are investigating the role of environmental regulation in stimulating technical progress in a context of a properly designed institutional framework. Moreover, considering the energy sector, and indirectly the Kyoto Protocol framework, what we are interested in is the OECD (and the EU particularly) area rather than an enlarged countries sample (Brazil for biofuels

for instance). Increasing the country sample and the typologies of HS codes could be the next research task. Finally, there is some scepticism on using national competitiveness measures (such as export flows or Foreign Directs Investment patterns) rather than more direct measures of productivity improvements in order to assess the effect of environmental regulation on firm's economic performance (Jaffe *et al.*, 1995). A narrower definition of the economic sector – as the specification here adopted - allows partially reducing this bias.
The variables included in the vectors of independent covariates are the following (see the Appendix Table A1 for the exact definition, the acronym and the data source for each variable):

M = Mass, explaining the role of income (GDP) and population size (POP) for countries *i* and *j*.

G = Geography, including geographic distances following the calculations provided by the CEPII (DIST), the geographic contiguity as a dummy variable (CONT), the existence of past colonial relationships as a dummy variable (COL), and the total land area as a dimensional variable (AREA).[1]

E = Environmental regulation, represented by the CO_2 emissions, the current environmental protection expenditures both of the public and the private sectors (CURE), the percentage of revenues from environmental taxes on total revenues (ENVTAX), and finally the public investments on environmental protection (ENVINV). All these measures of environmental regulation have been tested separately in order to reinforce the robustness of the empirical results. The environmental expenditures data provided by EUROSTAT allow describing directly the environmental regulation accounting for the expenditures sustained by private industries and the public sector in order to respect environmental standards. Unfortunately, using these variables has a great limitation, because we are forced to exclude completely other non-EU OECD countries. In order to test our model on the complete sample, we have adopted an indirect measure of environmental stringency as the level of CO_2 emission

[1] In this paper we have adopted as distance measure the simple distances, for which only one city is necessary to calculate international distances. There is also an alternative distance measure, given by the weighted distances, for which data on the principal cities in each country are necessary. The simple distances are calculated following the great circle formula, which uses latitudes and longitudes of the most important city (in terms of population) or of its official capital. The weighted distance measures use city-level data to assess the geographic distribution of population inside each nation. The idea is to calculate distance between two countries based on bilateral distances between the largest cities of those two countries, those inter-city distances being weighted by the share of the city in the overall country's population (Mayer and Zignago, 2006). Using weighted distances in our empirical analysis does not change significantly the obtained results.

(expressed as kg per unit of GDP at 2000 constant PPP international $). Using such an indirect measures give us the possibility to analyse two separate environment-trade relationship. The environmental stringency of the exporting country (country *i*) in this specific case gives an indication if environmental regulation is pushing technology advancements in industrialized countries, thus investigating the Porter and van der Linde hypothesis. On the contrary, the environmental stringency of the importing country (country *j*) gives us the dimension of the importance of an institutional framework in the trade partner. Considering that developing countries are excluded from any commitment in the Kyoto Protocol, if they are acting towards a reduction of CO_2 emissions per unit of GDP, it means that their development strategies are oriented towards energy savings and the adoption on renewable energies, thus revealing the effectiveness of the Kyoto Protocol even in its voluntary agreements.

I = Innovation, explained by alternative measures, such as the number of patents in the energy sector (ENEPAT), the number of total patents from residents (TOTPAT), the percentage of research and development expenditures (RD). The last two innovation variables were provided both for countries *i* and *j*, in order to control for the role of National Innovation Systems in explaining bilateral export flows by providing the correct environment for technological innovation (country *i*) and for international technological diffusion (country *j*), while ENEPAT is available only for exporting countries. Considering that even TOTPAT and RD are mainly available for developed countries, we have considered an alternative measure of technological diffusion specifically built for developing countries (TECDIFF), following the methodology adopted by Archibugi and Coco (2004). In this way, we have considered the capacity of the whole economic system to use and adopt the imported technologies, rather than the capacity to reproduce them (for the specific formulation of the ArCo index see the Appendix).

X = Other control variables for countries *j*, such as the importance of Foreign Direct Investment inflows (FDI), and the quality of the institutions expressed as the capacity to respect legal rules (RL), using the index of rule of law provided by the World Bank with the empirical work of Kauffman *et al*. (2003).[2]

[2] There are many alternative measures of institutional quality which are used in different empirical studies, such as the Corruption Perspectives Index provided by Transparency International (TICPI) that is considered more accurate than Rule of Law. The main problem is related to data availability for TICPI, while at the same time there is a high positive correlation between TICPI and Rule of Law index provided by the World Bank (Dasgupta *et al*., 2006).

5. EMPIRICAL RESULTS

The results of our empirical investigation show that a gravity equation model is a good framework of analysis to test our hypotheses. The first 2 columns of Table 1 report the results for the baseline gravity equation model in which only "structural" variables are considered. Very briefly, the higher the income level of both exporting and importing countries, the larger the trade flows even in the case of a specific sector as the one here analyzed. The distances between the trading partner plays as well a great role, where reduced distances are more favourable to increasing trade flows. Considering the negative sign associated to the size of population for both *i* and *j* countries, this is not so distant from other empirical results, meaning that in this specific case the role of the mass in attracting imports of advanced technologies is positively related to the level of income per capita rather than the number of potential consumers (given by the population size). In order to maintain the original formulation of the gravity equation, we have continued to include separately income and population.

Both Fixed Effects and Random Effects estimates are shown. However, the significance of the statistics associated to the Hausman test, gives clear indication that country individual effects are relevant in our analysis and that Fixed Effect estimates have to be preferred to the Random Effects ones. We found that this is true for all the model specifications we have tested and, therefore, we show only the results accounting for country individual effects (columns 3-5).[3]

Columns 3-5 of Table 1 show that environmental regulation plays an important role in shaping the bilateral export flows of environmental-friendly technologies in the energy sector. The coefficients associated to the more relevant proxies of environmental stringency (CURE and CO_2) are in fact strongly significant and show the expected signs. While for the variable explaining efforts in environmental protection (CURE) the higher the value the more stringent is environmental regulation, CO_2 emissions should be considered as an indirect proxy of environmental standards. If a country is applying stringent (and efficient) environmental regulation, the level of CO_2 emissions will be lesser. In this case we have adopted CO_2 emissions because there is a complete dataset for this pollutant for all the

[3] Considering results from fixed effects models, the coefficients associated to the size of the exporter's economy (GDPi) are higher than those related to the importers (GDPj), and this is consistent with theoretical results reported by Feenstra *et al*. (2001) for the case of "differentiated goods", where the domestic-income elasticity exceeds the partner-income elasticity.

countries and years analysed, thus allowing the largest sample easy to estimate. Moreover, in this case we can consider environmental regulation even for the importing countries, thus exploring the hypothesis that even the standards in the receiving countries could be possible drivers of technological diffusion. Finally, CO_2 emissions are closely related to the Kyoto Protocol commitments (our properly designed environmental regulation) and this is, at the best of our knowledge, the only proxy variable giving an approximation of countries' efforts to respect Kyoto abatement targets. The expected sign for CO_2 related to country *j* is correct in all the three models, but it is never statistically significant, thus not confirming that this could be a driver for technological imports.

Summing up, we could say that CURE is the variable which better represents the efforts made by private firms (compliance costs) to respect environmental regulation, while CO_2 emissions are a proxy of the overall national efforts to respect the standards.

>> INSERT TABLE 1 AROUND HERE <<

The second step of our empirical analysis is to introduce in our econometric model technological variables which account for the strength of national innovation systems (ENEPAT, TOTPAT, and RD). The results reported in Table 2 confirm our hypothesis that the national innovative capacity of exporters plays a crucial role in affecting their ability to penetrate the international market for energy technologies. In order to test the robustness of our results we have performed different specifications of the model, using alternative measures of both environmental regulations' stringency and of technological competencies. In Columns 1-3 we show the results for the models in which CO_2 has been used as a proxy for environmental regulation in countries *i* and different technological variables are alternatively introduced. It emerges that the intensity of research activities of exporters (either measured in terms of R&D expenditures or in terms of patent applications) has a positive and significant effect on the export performance of the countries considered in the analysis. In particular, the results of Column 3 show that the stronger technological specialization is in the field of energy production, transmission and distribution (expressed by ENEPAT), the higher is the gain in terms of comparative advantages in terms of trade flows of energy technologies. These results are confirmed also when CURE is used as a measure of environmental regulation in exporting countries (Columns 4-6). The variables concerning the regulatory activities and technological capacities of importing countries (both measured in terms of R&D intensity, RD, or in terms of our indicator of technological diffusion, TECDIFF, as in Columns 7 and 8) are not significant. This implies that these two aspects are not relevant in explaining bilateral export flows of the particular kind of products we are investigating. This result is consistent with the previous considerations about the role of environmental regulation implemented in the importing countries. Therefore, it seems to emerge that the major drivers for relative comparative advantages are the environmental regulation and the quality of the innovation system of the exporters.

>> INSERT TABLE 2 AROUND HERE <<

Finally, the results for the full model, in which other control variables such as the flow of Foreign Direct Investments and the proxy for the quality of institutions in importer countries are introduced, are shown in Table 3 where also we report the results of the robustness checks we have carried out. The first two columns show the output for the full model using alternative regulation and technological variables. The results are stable and also the additional variables used significantly enter in the model with the expected signs. In particular, two robustness checks have been performed to address the problems of heteroskedasticity and potential endogeneity of the regressors relative to environmental regulation. The role of endogenous environmental regulation in the analysis of relationships between stringent standards and trade flow has been recently addressed by Jug and Mirza (2005) in a specific gravity equation model, and more generally by Ederington and Minier (2003) and Levinson and Taylor (2004), in the detection of the existence of pollution haven effects.

Going into details, in order to verify if potential problems of heteroskedasticity affect our results, we have relaxed the assumption of time-invariant variance in the idiosyncratic errors by applying the FEGLS estimator. Columns 3 and 4 contain the results of these robust estimates. Since differences in the magnitude and the significance of the coefficients are modest with respect to the FE estimator, it is possible to conclude that heteroskedasticity has not seriously biased previous figures. Second, the two versions of the full model have been tested using the Instrumental Variable estimator (IV) in order to check if the potential endogeneity of the variables relative to environmental regulation has affected our results. We follow the standard procedure of using lagged levels (two periods back) of the endogenous covariate as instrument after controlling for individual effects. The results obtained by applying this technique are showed in column 5 and 6 of Table 3. Since the results obtained with the use of appropriate instruments are consistent with those obtained with the FE estimator we conclude that the potential bias in our previous estimates is of minor relevance here.

6. CONCLUSIONS

In this paper we have tested an empirical model based on a gravity equation in order to provide evidence of the relevance of the Porter and van der Linde hypothesis. Empirical results show that a more stringent environmental regulation provides a positive impulse for increasing investments in advanced technological equipments, thus providing an indirect source of comparative advantages at international level. Countries with stringent environmental standards have a higher export capacity for those environmental-friendly technologies that regulation induces to adopt. Far from contrasting empirical results on the existence of a pollution haven effects, the aim of the paper was to test if a proper institutional framework such as a properly designed environmental regulation could be considered as a positive impulse to competitiveness rather than a limit to economic development. Applying a gravity equation on a very specific definition of environmental technologies, focusing on the energy sector, what strongly emerges is the positive effects of both environmental regulation and the effectiveness of national innovation systems. These results seem to reinforce the European strategies addressed in the recent policy papers edited by the Commission (EC, 2004, 2006a, 2006b, 2007) where environmental protection and energy security initiatives could be well integrated in the wider Lisbon strategy for economic growth, innovation and employment.

The next research agenda would include, among the other, the construction of a direct environmental regulation measure valid for all the OECD countries (and not only for the European Union), the construction of a more general dependent variable including all high technology environmental protection activities, and finally the realization of a system of equations in order to analyse the possible endogenous mechanisms involving the innovation system and the regulatory framework.

REFERENCES

Albrecht, J., 1998, Environmental Costs and Competitiveness. A Product-Specific Test of the Porter Hypothesis, *Working Paper* n. 50, University of Ghent, Belgium.

Altman, M., 2001, When green isn't mean: economic theory and the heuristics of the impact of environmental regulations on competitiveness and opportunity cost, *Ecological Economics*, n. 36, pp. 31-44.

Anderson, J.E., 1979, A Theoretical Foundation for the Gravity Equation, *American Economic Review* Vol. 69 (1), pp. 106-116.
Antweiler, W., Copeland, B.R., Taylor, M.S., 2001, Is Free Trade Good for the Environment?, *The American Economic Review*, Vol. 91 (4), pp. 877-908.
Archibugi, D., Coco, A., 2004, A New Indicator of Technological Capabilities for Developed and Developing Countries (ArCo), *World Development*, Vol. 32 (4), pp. 629-654.
Bernauer, T., Engels, S., Kammerer, D., Seijas, J., 2006, Explaining Green Innovation, *CIS Working Paper* n. 17, ETH Zurich and University of Zurich.
Bommer, R., 1999, Environmental Policy and Industrial Competitiveness: The Pollution-Haven Hypothesis Reconsidered, *Review of International Economics*, Vol. 7 (2), pp. 342-355.
Bovenberg, A.L., Smulders, S., 1995, Environmental quality and pollution-augmenting technological change in a two-sector endogenous growth model, *Journal of Public Economics*, n. 57, pp. 369-391.
Bretschger, L., Economics of technological change and the natural environment: How effective are innovations as a remedy for resource scarcity?, *Ecological Economics*, n. 54, pp. 148-163.
Brock, W.A., Taylor, M.S., 2004, Economic Growth and the Environment: A Review of Theory and Empirics, *NBER Working Paper* n. 10854, Cambridge, MA, USA.
Brunnermeier, S.B., Cohen, M.A., 2003, Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management*,no. 45, pp. 278-293.
Buchanan, J.M., Tullock, G., 1975, Polluters' Profit and Political Response: Direct Controls versus Taxes, *The American Economic Review*, Vol. 65 (1), pp. 139-147.
Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), 2006, *Dataset of distances measures*, CEPII, Paris.
Cerin, P., 2006, Bringing economic opportunity into line with environmental influence: A discussion on the Coase theorem and the Porter and van der Linde hypothesis, *Ecological Economics*, n. 56, pp. 209-225.
Commission of the European Communities (EC), 2004, *Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union*, COM(2004) 38 final, Brussels.
Copeland, B.R., Taylor, M.S., 2003, *Trade and the Environment: Theory and Evidence,* Princeton University Press, U.S.A.
Copeland, B.R., Taylor, M.S., 2004, Trade, Growth, and the Environment, *Journal of Economic Literature*, Vol. 42 (1), pp. 7-71.
Copeland, B.R., Taylor, M.S., 2005, Free trade and global warming: a trade theory view of the Kyoto protocol, *Journal of Environmental Economics and Management*, n. 49, pp. 205-234.
Dasgupta, S., Hamilton, K., Pandey, K., Wheeler, D., 2006, Environment During Growth: Accounting for Governance and Vulnerability, *World Development*, forthcoming.
Davis, D.R., Weinstein, D.E., 1996, Does economic geography matter for international specialization?, NBER Working Paper n. 5706.
Deardorkk, A., 1998, Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?, ch.1 in Frankel, J.A. (ed.), *The Regionalization of the World Economy*, Chicago, The University of Chicago Press.
Ederington, J., Minier, J., 2003, Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis, *Canadian Journal of Economics*, Vol. 36 (1), pp. 137-154.
Ederington, J., Levinson, A., Minier, J., 2005, Footloose and Pollution-Free, *Review of Economics and Statistics*, Vol. 87 (1), pp. 283-306.
European Commission (EC), 2004, *Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union*, COM(2004) 38 final, Brussels.
European Commission (EC), 2006a, *A European Strategy for Sustainable, Competitive and Secure Energy*, COM(2006) 105 final, Brussels.
European Commission (EC), 2006b, *Limiting Global Climate Change to 2 degrees Celsius Policy options for the EU and the world for 2020 and beyond*, SEC(2006) 27-11-2006, Brussels.
European Commission (EC), 2007, *An Energy Policy for Europe*, COM(2007) 03-01-2007, Brussels.
EUROSTAT, 2006, *Environmental Accounting on-line database*, Luxemburg.
Evenett, S.J., Keller, W., 2002, On Theories Explaining the Success of the Gravity Equation, *Journal of Political Economy*, Vol. 110 (2), pp. 281-316.
Feenstra, R.C., Markusen, J.R., Rose, A.K., 2001, Using the gravity equation to differentiate among alternative theories of trade, *Canadian Journal of Economics*, Vol. 34 (2), pp. 430-447.
Gholami, R., Lee, S-Y.T., Heshmati, A., 2006, The Causal Relationship Between Information and Communication Technology and Foreign Direct Investment, *World Economy*, Vol. 29 (1), pp. 43-62.
Grether, J.-M., De Melo, J., 2003, Globalization and Dirty Industries: Do Pollution Havens Matter?, *NBER Working Paper* n. 9776, Cambridge, MA, USA.
Harris, M.N., Kónya, L., Mátyás, L., 2002, Modelling the Impact of Environmental Regulations on Bilateral Trade Flows: OECD, 1990-1996, *World Economy*, Vol. 25 (3), pp. 387-405.
Hoekman, B.M., Maskus, K.E., Saggi, K., 2005, Transfer of Technology to Developing Countries: Unilateral and Multilateral Policy Options, *World Development*, Vol. 33 (10), pp. 1587-1602.

Jaffe, A.B., Palmer, K., 1997, Environmental Regulation and Innovation: A Panel Data Study, *The Review of Economics and Statistics*, Vol. 79 (4), pp. 610-619.
Jaffe, A.B., Stavins, R.N., 1995, Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion, *Journal of Environmental Economics and Management*, n. 29, pp. 43-63.
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2000, Technological Change and the Environment, *NBER Working Paper* n. 7970, Cambridge, MA, USA.
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005, A tale of two market failures: Technology and environmental policy, *Ecological Economics*, n. 54, pp. 164-174.
Jaffe, A.B., Peterson, S.R., Portney, P.R., Stavins, R.N., 1995, Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?, *Journal of Economic Literature*, Vol. 33 (1), pp. 132-163.
Jug, J., Mirza, D., 2005, Environmental Regulations in Gravity Equations: Evidence from Europe, *World Economy*, Vol. 28 (11), pp. 1591-1615.
Keller, W., 2004, International Technology Diffusion, *Journal of Economic Literature*, Vol. 42 (3), pp. 752-782.
Kaufman, D., Kraay, A., Mastruzzi, M., 2003, *Governance Matters III: Governance Indicators for 1996-2002*, The World Bank, Washington DC.
Lanjouw, J.O., Mody, A., 1996, Innovation and the international diffusion of environmentally responsive technology, *Research Policy*, n. 25, pp. 549-571.
Lanoie, P., Laplante, B., Roy, M., 1998, Can capital market create incentives for pollution control?, *Ecological Economics*, n. 26, pp. 31-41.
Letchumanan, R., Kodama, F., 2000, Reconciling the conflict between the ‘pollution-haven’ hypothesis and an emerging trajectory of international technology transfer, *Research Policy*, n. 29, pp. 59-79.
Levinson, A., Taylor, S., 2004, Unmasking the Pollution Haven Effect, *NBER Working Paper* n. 10629, Cambridge, MA, USA.
Mayer, T., Zignago, S., 2006, Notes on CEPII’s distances measures, Centre d’Etudes Prospectives et d’Informations Internationales (CEPII), Paris.
Mulatu, A., Florax, R.J., Withagen, C.A., 2001, Environmental Regulation and Competitiveness: A Meta-Analysis of International Trade Studies, *Tinbergen Institute Discussion Paper* n. 39, Tinbergen Institute, Amsterdam.
Murty, M.N., Kumar, S., 2003, Win-Win Opportunities and Environmental Regulation: Testing of Porter Hypothesis for Indian Manufacturing Industries, *Journal of Environmental Management*, Vol. 67 (2), pp. 139-144.
Neary, J.P., 2006, International Trade and the Environment: Theoretical and Policy Linkages, *Environmental & Resource Economics*, No. 33, pp. 95-118.
Newell, R.G., Jaffe, A.B., Stavins, R.N., 1999, The Induced Innovation Hypothesis and Energy-Saving Technological Change, *The Quarterly Journal of Economics*, Vol. 114 (3), pp. 941-975.
Palmer, K., Oates, W.E., Portney, P.R., 1995, Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm?, *Journal of Economic Perspectives*, Vol. 9 (4), pp. 119-132.
Popp, D., 2005, Lessons from patents: Using patents to measure technological change in environmental models, *Ecological Economics*, n. 54, pp. 209-226.
Porter, M.E., van der Linde, C., 1995, Toward a New Conception of the Environment-Competitiveness Relationship, *Journal of Economic Perspectives*, Vol. 9 (4), pp. 97-118.
Requate, T., 2005, Dynamic incentives by environmental policy instruments – a survey, *Ecological Economics*, n. 54, pp. 175-195.
Steenblik, R., 2005, Liberalisation of Trade in Renewable-Energy Products and Associated Goods: Charcoal, Solar Photovoltaic Systems, and Wind Pumps and Turbines, *OECD Trade and Environment Working Paper* n. 2005-07, OECD, Paris.
Tinbergen, J., 1962, *Shaping the World Economy*, The Twentieth Century Fund, New York.
United Nations Conference on Trade and Development (UNCTAD), 2006, *COMTRADE on-line database*, UN.
United States Patent and Trademark Office (USPTO), 2006.
Van Beers, C., van den Bergh, J.C.J.M., 2000, The Impact of Environmental Policy on Foreign Trade, *Tinbergen Institute Discussion* Paper n. 69, Amsterdam.
Vollebergh, H.R.J., Kemfert, C., 2005, The role of technological change for a sustainable development, *Ecological Economics*, n. 54, pp. 133-147.
Wagner, M., 2003, *The Porter Hypothesis Revisited: A Literature Review of Theoretical Models and Empirical Tests*, Centre for Sustainability Management, Univesitat Luneburg, Germany.
Wheeler, D., 2001, Racing to the Bottom? Foreign Investment and Air Pollution in Developing Countries, *World Bank Policy Research Working Paper* n. 2524, The World Bank, Washington DC.
World Bank, 2006, *World Development Indicators (WDI)*, on-line database, The World Bank, Washington DC.

TABLE 1 – BASIC GRAVITY EQUATION AND THE ROLE OF ENVIRONMENTAL REGULATION

	(1) FE	(1) RE	(3)	(4)	(5)
GDPj	0.548*	1.137*	0.486*	0.429*	0.410*
	(4.61)	(37.04)	(3.95)	(3.09)	(2.95)
GDPi	1.953*	0.222**	1.929*	3.039*	3.742*
	(28.62)	(2.14)	(28.20)	(35.22)	(42.59)
POPj	-2.138*	-0.467*	-2.228*	-2.544*	-2.839*
	(-7.15)	(-10.93)	(-7.29)	(-7.33)	(-8.14)
POPi	-0.941*	0.694*	-0.900*	-1.908*	-2.704*
	(-13.67)	(6.38)	(-13.04)	(-22.15)	(-30.86)
DIST	-1.589*	-0.997*	-1.540*	-1.325*	-1.248*
	(-74.79)	(-22.77)	(-69.60)	(-28.91)	(-27.24)
COL	1.419*	1.619*	1.393*	1.273*	1.293*
	(27.16)	(9.52)	(26.53)	(23.65)	(24.19)
CONT	-0.282*	0.784*	-0.230*	-0.005	0.035
	(-3.36)	(2.96)	(-2.74)	(-0.05)	(0.36)
AREA	-0.114***	0.024	1.102*	1.269*	1.391*
	(-1.68)	(0.91)	(8.88)	(8.98)	(9.80)
CO_2j			-0.022	-0.04	-0.051
			(-0.32)	(-0.53)	(-0.68)
CO_2i			-0.277*		
			(-7.67)		
CUREi				0.041*	
				(8.85)	
ENVINVi					-0.002
					(-0.20)
CONST	40.548*	-5.423*	24.478*	28.884*	35.924*
	(11.16)	(-6.94)	(8.79)	(9.00)	(9.21)
Adj R^2	0.70	0.54	0.70	0.71	0.73
Obs	20342	20342	20125	14253	13557
Hausman	13687.18*				

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.

TABLE 2 – TESTING THE ROLE OF THE NATIONAL INNOVATION SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
GDPj	0.686*	0.578**	0.962*	0.951*	0.781*	1.021*	0.643*	0.753*
	(2.76)	(2.37)	(3.82)	(3.57)	(2.83)	(3.57)	(3.89)	(4.08)
GDPi	1.100*	2.157*	1.076*	1.182*	2.457*	2.124*	1.087*	2.760*
	(8.86)	(18.89)	(7.14)	(8.13)	(16.94)	(9.04)	(10.95)	(14.58)
POPj	-2.699*	-3.538*	-2.579*	-2.960*	-3.476*	-2.939*	-2.024*	-2.158*
	(-3.47)	(-4.58)	(-3.24)	(-3.55)	(-4.00)	(-3.28)	(-5.59)	(-5.24)
POPi	-0.092	-1.180*	-0.058	0.001	-1.371*	-0.938*	-0.112	-1.582*
	(-0.73)	(-10.32)	(-0.39)	(0.01)	(-9.57)	(-4.15)	(-1.11)	(-8.67)
DIST	-1.524*	-1.514*	-1.498*	-1.175*	-1.231*	-1.303*	-1.571*	-1.375*
	(-54.05)	(-56.08)	(-57.44)	(-21.93)	(-22.35)	(-21.88)	(-64.38)	(-24.46)
COL	0.917*	0.997*	0.957*	0.917*	0.954*	0.996*	1.398*	1.258*
	(12.33)	(13.27)	(12.35)	(11.93)	(11.94)	(12.42)	(26.01)	(22.75)
CONT	-0.319*	-0.368*	-0.311*	-0.017	-0.077	-0.05	-0.320*	-0.141
	(-3.30)	(-3.80)	(-3.16)	(-0.16)	(-0.69)	(-0.45)	(-3.51)	(-1.31)
AREA	1.647*	2.253*	1.576*	1.756*	2.021*	1.568*	0.966*	-0.107
	(4.34)	(6.01)	(3.65)	(3.88)	(4.77)	(3.50)	(6.18)	(-1.14)
CO_2j	-0.004	-0.044	-0.094	0.076	0.05	0.078	-0.013	0.029
	(-0.02)	(-0.26)	(-0.55)	(0.42)	(0.26)	(0.41)	(-0.18)	(0.32)
CO_2i	-0.383*	-0.356*	-0.302*				-0.258*	
	(-6.87)	(-7.19)	(-6.14)				(-6.02)	
CUREi				0.071***	0.045*	0.038*		0.027*
				(10.52)	(6.21)	(5.62)		(5.08)
RDi	0.712*			0.914*			0.642*	
	(17.61)			(21.11)			(20.31)	
TOTPATi		0.110*			0.174*			
		(6.64)			(8.50)			
ENEPATi			0.137*			0.270*		0.249*
			(8.19)			(14.44)		(17.21)
RDj	-0.028	-0.008	0.017	-0.195	-0.116	-0.088		
	(-0.24)	(-0.07)	(0.15)	(-1.55)	(-0.88)	(-0.68)		
TECDIFFj							-0.351	-0.391
							(-1.53)	(-1.46)
CONST	19.774*	30.068*	19.182*	16.931**	26.884*	20.554*	19.288*	37.464*
	(3.26)	(5.01)	(2.68)	(2.27)	(3.95)	(2.88)	(5.52)	(6.84)
Adj R^2	0.74	0.73	0.76	0.76	0.74	0.78	0.72	0.75
Obs	8002	8592	7436	6155	6256	5100	15779	10277

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.

TABLE 3 – TESTS FOR ROBUSTNESS

	(1)	(2)	(1) GLS	(2) GLS	(1) IV	(2) IV
GDPj	0.732*	0.543*	0.823*	0.770*	0.909*	0.553**
	(4.84)	(3.33)	(9.87)	(8.17)	(4.57)	(2.57)
GDPi	0.995*	1.192*	0.754*	1.347*	0.392*	0.666*
	(8.38)	(9.71)	(13.10)	(18.51)	(2.74)	(4.60)
POPj	-1.566*	-1.674*	-1.673*	-2.034*	-1.804*	-1.934*
	(-4.11)	(-4.06)	(-9.32)	(-8.81)	(-3.23)	(-3.21)
POPi	-0.035	-0.03	0.210*	-0.207*	0.541*	0.492*
	(-0.29)	(-0.25)	(3.58)	(-2.87)	(3.77)	(3.40)
DIST	-1.541*	-1.363*	-1.509*	-1.383*	-1.557*	-1.328*
	(-66.87)	(-27.67)	(-125.77)	(-56.63)	(-58.62)	(-23.64)
COL	1.300*	1.216*	1.121*	1.004*	1.259*	1.182*
	(23.00)	(21.18)	(40.66)	(32.24)	(19.38)	(18.08)
CONT	-0.393*	-0.151	-0.331*	-0.166*	-0.445*	-0.129
	(-4.06)	(-1.47)	(-9.87)	(-4.43)	(-3.94)	(-1.09)
AREA	-0.102	0.059	-0.072	0.105**	-0.084	0.076
	(-1.17)	(0.63)	(-1.60)	(1.98)	(-0.70)	(0.60)
CO_2j	0.045	-0.001	-0.007	0.013	-0.007	-0.065
	(0.56)	-(0.02)	(-0.14)	(0.26)	(-0.07)	(-0.66)
CO_2i	-0.181*		-0.085*		-0.161*	
	(-4.61)		(-4.26)		(-3.48)	
CUREi		0.063*		0.042*		0.088*
		(11.31)		(15.40)		(9.02)
RDi		0.815*		0.719*		0.919*
		(22.85)		(38.05)		(23.16)
ENEPATi	0.106*		0.094*		0.122*	
	(7.97)		(13.28)		(8.01)	
FDIj	0.051*	0.038**	0.032*	0.016***	0.037***	0.028
	(2.99)	(2.00)	(4.10)	(1.74)	(1.81)	(1.26)
RLj	0.280*	0.386*	0.292*	0.281*	0.174	0.336**
	(2.94)	(3.81)	(5.90)	(5.32)	(1.39)	(2.57)
CONST	26.161*	23.305*	23.557*	24.729*	26.345*	24.721*
	(5.40)	(4.44)	(4.41)	(3.11)	(3.69)	(3.18)
Adj R^2	0.74	0.73			0.74	0.73
Obs	13788	11347	13788	11347	10551	8912

Statistics for t-Student in parenthesis. * p-values < 0.01, ** p-values < 0.05, *** p-values < 0.1.

APPENDIX – VARIABLES DESCRIPTION AND METHODOLOGY

TABLE A1 – DEFINITION OF VARIABLES, STATISTIC SOURCES AND ACRONYMS

Variable	Definition	Source
	Dependent variable	
EXPij	Bilateral export flows in renewable energies and energy saving technologies (at constant 2000$ PPP) (HS definition Table A2)	UNCTAD
	Mass	
GDPi and j	Natural logarithm of GDP (constant 2000 US$)	WDI
POPi and j	Natural logarithm of total population	WDI
AREAj	Natural logarithm of land area (sq. km)	WDI
	Geography	
DISTj	Geographic distances ()	CEPII
COLj	Existence of colonial relationships (dummy variable)	CEPII
CONTj	Geographic contiguity (dummy variable)	CEPII
	Environmental regulation	
CO_2i and j	Natural logarithm of CO_2 emission (kg per 2000 PPP $ of GDP)	WDI
CUREi	Current environmental protection expenditure (public+industry) as % of GDP	EUROSTAT
ENVTAXi	Revenues from environmental taxes as % of total tax revenues	EUROSTAT
ENVINVi	Public Environmental investments as % of GDP	EUROSTAT
	Innovation	
RDi and j	Research and development expenditure as % of GDP	WDI
TOTPATi and j	Patent applications, residents (per 100.000 people)	WDI
ENEPATi	Natural logarithm of the moving average of the number of patents in the class "equipment for production, distribution or transformation of energy" (% of total patents from residents)	USPTO
TECDIFFj	Technological diffusion (ARCO index methodology)	WDI
	Other control variables	
FDIj	Total FDI inflows as % of GDP	WDI
RLj	Rule of Law (Kauffman et al., 2003)	World Bank

Considering that human skills are widely represented by the human development dimensions, we have built a new technological index based only on two out the four components proposed by Archibugi and Coco (2004). In order to represent the technological infrastructures we have accounted for internet and telephone penetration (number of internet, fixed and mobile telephone lines per 1.000 persons). The final formulation of this index (named TECDIFF) is as follows:

$$TECDIFF = \frac{1}{2}\left(\frac{\ln(TEL_i)}{\ln(TEL_{\max}} + \frac{INTERNET_i}{INTERNET_{\max}}\right) \qquad [4]$$

As we can see, the formulation of the ARCO index is based on the same methodology adopted for the HDI, where the observed values are normalised by a minimum and maximum value. In this case the minimum value is always equal to zero, while the maximum value has been taken in the whole time period/countries sample considered in this work. This formulation gives the possibility to account for temporal changes at country level, as well as the methodology adopted by UNDP for the HDI. Following the UNDP methodology, the component related to telephone users has been considered in a logarithm form, creating "a threshold above which the technological capacity of a country is no longer enriched by the use of telephones" (Archibugi and Coco, 2004, p. 635). We have not considered the electricity consumption within the technological infrastructures because there are other energy related variables in our model.

TABLE A2 - TECHNOLOGIES FOR RENEWABLE ENERGIES AND ENERGY SAVINGS, HS 1996

Code	**Description**
	Renewable energies
2207.10	Ethanol
2905.11	Methanol
4401.10	Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms
4401.30	Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms
7321.13	Cooking appliances and plate warmers for solid fuel, iron or steel
7321.83	Non electrical domestic appliances for liquid fuel
8410.11	Of a power not exceeding 1,000kW
8410.12	Of a power exceeding 1,000 kW but not exceeding 10,000 kW
8410.13	Of a power exceeding 10,000 kW. 8410.90 – Parts, including regulators
8410.90	Hydraulic turbines and water wheels; parts, including regulators
8413.81	Pumps for liquids, whether or not fitted with a measuring device; [Wind turbine pump]
8419.11	Instantaneous gas water heaters
8419.19	Instantaneous or storage water heaters, non-electric — other [solar water heaters]
8502.31	Electric generating sets and rotary converters — Wind powered
8502.40	Electric generating sets and rotary converters [a generating set combining an electric generator and either a hydraulic turbine or a Sterling engine]
8541.40	Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light-emitting diodes
	Energy savings and management
3815.00	Catalysts
7008.00	Multiple-walled insulating units of glass
7019.90	Other glass fibre products
8404.20	Condensers for steam or other vapour power units
8409.99	Parts suitable for use solely or principally with the engines of HS 8407 or 8408; other
8418.69	Heat pumps
8419.50	Heat exchange units
8419.90	Parts for heat exchange equipment
8539.31	Fluorescent lamps, hot cathode
8543.19	Fuel cells
9028.10	Gas supply, production and calibrating metres
9028.20	Liquid supply, production and calibrating metres
9032.10	Thermostats

Source: Steenblick (2005).

TABLE A3 – MAIN STATISTICS

Variable	No. Obs.	Mean	Std. Dev.	Min	Max
EXPij	24766	6.38	2.86	-3.91	14.37
GDPi	29600	13.16	1.22	11.22	16.23
GDPj	24320	10.93	1.82	6.87	16.19
POPi	29600	16.79	1.20	15.11	19.51
POPj	29400	15.95	1.78	11.04	20.99
DIST	29600	6637	4249	60	19586
AREAj	29200	831078	2083308	50	16400000
CO_2i	29600	-0.98	0.34	-1.71	-0.29
CO_2j	27200	-0.99	0.92	-3.91	1.29
CUREi	20720	1.58	0.71	-0.73	2.65
ENVTAXi	23680	1.98	0.22	1.59	2.42
ENVINVi	19240	1.91	1.44	0.10	6.10
Rdi	21312	0.58	0.48	-0.67	1.45
RDj	11440	-0.41	1.05	-4.61	1.61
TOTPATi	22940	3.04	1.24	-0.35	5.71
TOTPATj	11920	1.16	2.16	-5.44	5.71
ENEPATi	19240	-1.41	1.04	-3.35	0.78
TECDIFFj	28520	0.41	0.20	0.00	1.06
FDIj	25260	0.75	1.30	-4.61	4.54
RLj	29220	0.09	1.00	-2.03	2.71

TABLE A4 – CORRELATION MATRIX

	COLj	CONTj	RLj	TECDIFFj	ENVINVi	GDPi	GDPj	DISTj	AREAj	CO_2j
COLj	0.22									
CONTj	0.04	0.17								
RLj	0.04	0.10	0.74							
TECDIFFj	-0.03	0.08	-0.01	-0.20						
ENVINVi	0.09	0.06	0.00	0.02	-0.04					
GDPi	0.07	0.11	0.30	0.16	-0.01	0.00				
GDPj	0.03	-0.41	-0.21	-0.21	0.01	0.02	0.07			
DISTj	0.09	-0.03	-0.20	-0.20	0.02	0.00	0.61	0.20		
AREAj	0.03	-0.08	-0.39	-0.19	0.02	-0.01	-0.13	-0.02	0.06	
CO_2j	-0.04	-0.01	-0.01	-0.09	0.08	-0.14	-0.01	0.01	0.01	0.01
POPj	0.05	0.02	-0.14	-0.24	0.02	0.00	0.88	0.22	0.73	0.01
POPi	0.09	0.05	0.00	0.00	-0.02	0.90	0.00	0.03	0.00	-0.01
CUREi	-0.03	-0.01	-0.01	-0.02	0.01	-0.45	-0.01	-0.06	0.00	0.01
ENVTAXi	0.05	0.05	0.00	-0.05	0.03	0.77	0.00	0.02	0.00	0.01
ENEPATi	-0.13	-0.04	0.02	0.09	-0.09	-0.61	0.01	-0.02	-0.01	-0.01
TOTPATj	-0.01	0.15	0.61	0.65	-0.04	0.00	0.29	-0.29	-0.07	0.08
TOTPATi	0.01	0.04	0.02	0.08	-0.07	0.10	0.01	-0.03	-0.01	-0.01
RDj	0.03	0.17	0.71	0.70	-0.04	0.00	0.46	-0.31	-0.04	-0.09
RDi	-0.07	0.00	0.02	0.14	-0.31	-0.30	0.01	-0.06	-0.02	-0.02
FDIj	0.00	0.03	0.03	0.11	-0.05	0.00	-0.29	-0.11	-0.31	0.17

	CO_2i	POPj	POPi	CUREi	ENVTAXi	ENEPATi	TOTPATj	TOTPATi	RDj	RDi
POPj	0.01									
POPi	-0.14	0.00								
CUREi	0.18	0.00	-0.48							
ENVTAXi	0.14	0.00	0.77	-0.35						
ENEPATi	0.17	-0.01	-0.60	0.16	-0.28					
TOTPATj	-0.02	-0.05	-0.01	0.00	-0.01	0.03				
TOTPATi	0.21	-0.01	0.10	0.04	0.25	0.25	0.02			
RDj	-0.03	0.08	0.00	-0.01	-0.01	0.03	0.81	0.02		
RDi	0.16	-0.02	-0.31	0.38	-0.16	0.60	0.04	0.67	0.04	
FDIj	-0.01	-0.33	0.00	0.01	-0.02	0.02	-0.06	-0.01	-0.08	0.01

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(lxxxi) This paper was presented at the EAERE-FEEM-VIU Summer School on "Computable General Equilibrium Modeling in Environmental and Resource Economics", held in Venice from June 25th to July 1st, 2006 and supported by the Marie Curie Series of Conferences "European Summer School in Resource and Environmental Economics".

(lxxxii) This paper was presented at the Workshop on "Climate Mitigation Measures in the Agro-Forestry Sector and Biodiversity Futures", Trieste, 16-17 October 2006 and jointly organised by The Ecological and Environmental Economics - EEE Programme, The Abdus Salam International Centre for Theoretical Physics - ICTP, UNESCO Man and the Biosphere Programme - MAB, and The International Institute for Applied Systems Analysis - IIASA.

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