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BIOFUELS PUBLIC SUPPORT AND TECHNOLOGICAL PATHS IN THE ENERGY SECTOR

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Biofuels public support and technological paths in the energy sector

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Abstract
The last years have experienced a dramatic increase in oil prices together with growing concern about the consequences of carbon emissions from fossil fuels in the transport sector. Interest in producing biofuels from agricultural crops has arisen at worldwide level because they are an inexhaustible energy source and they could have a positive impact on reducing CO_2 emissions. While biofuels production seems to be an appealing sector to solve problems both for energy security and climate change, it should be taken into account it represents a sector where subsidies are pervasive and large in extent. The huge increase in biofuels production presents controversial effects in terms of: i) the energy accounting; ii) the conflict between energy vs. food destination of energy crops; iii) the distortion of the innovation path. The aim of this paper is to investigate the third aspect, the only one that has not been yet deeply analysed. By using a gravity equation model we study if public support devoted to the biofuels sector has a negative impact on the technological path, by diverting public and private investments from other renewable energies and energy savings technologies. Our results clearly show that policies supporting biofuels production are responsive for negative effects on comparative advantages particularly in the energy saving technologies sector.

Keywords: Biofuels, Public Support, International Competitiveness, Energy Sector, Technological Innovation
J.E.L. classification: F18; F21; H23; Q42; Q48; Q55; Q56

1. INTRODUCTION

The last years have experienced a dramatic increase in oil prices together with growing concern about the consequences of carbon emissions from fossil fuels in the transport sector. As reported in the "Energy, Transport and Environment Indicators" published by Eurostat (2007), in 2005 the transport sector was responsible for about 31% of total energy consumption in the European Union (EU-27 Members), while emitting the 19% of total Greenhouse Gases (GHGs) emissions. The ten years between 1995 and 2005 have marked a 21% increase in consumption in transport, which is mainly driven by consumption for road transport, which has a predominant share (82%) of total transport consumption. Considering that crude oil represents the 96% of total energy consumption in the road sector, the 17% increase in GHGs emissions during this decade from the transport sector is fully explained. This trend in energy consumption over the past ten years shows that European policies for a sustainable energy are insufficient in this specific sector, highly dependent from fossil fuels, thus reinforcing the interest in alternative energy sources.

Interest in producing biofuels from agricultural crops has arisen at worldwide level, and not only in the EU, because they are an inexhaustible energy source and they could have a positive impact on reducing CO_2 emissions. While biofuels production seems to be an appealing sector to solve problems both for energy security and climate change, it should be taken into account that – mainly because of pressures by agricultural lobbies both in the EU and the United States - it represents a sector where subsidies are pervasive and large in extent. This has important implications in terms of cost effectiveness of this instrument and in terms of the achievement of energy and environmental goals.

In particular, the huge increase in biofuels production presents controversial effects mainly in three aspects: i) the energy accounting; ii) the conflict between energy and food destination of agricultural crops; iii) the distortion of the innovation path. While the first two points have been extensively analysed by many contributions from academicians and international organizations, the third one has not been deeply analysed. Competition in allocation of land between food and bioenergy feedstock have been extensively analyzed specially with regard to the US where almost 20% of corn area is devoted to ethanol production and where strong expansion is envisioned to fulfil the renewable fuel standard (Togkoz *et al*., 2007). Other studies investigate on the impact of the biofuel mandate on European agriculture and on agricultural trade (OECD, 2005).

As biofuels are just one of the existing alternative technologies currently available for addressing energy and environmental goals, the huge bulk represented by biofuels support policies may not be neutral in terms of technical progress generation in the renewables and energy saving technologies.

The aim of this paper is to investigate if public support devoted to the biofuels sector has a negative impact on the technological path, by diverting public and private investments from other renewable energies and energy savings technologies.

For this purpose we have adopted a gravity equation models based on bilateral export flows of technologies for production and consumption of renewable energies (wind, solar and photovoltaic, fuel cells) and energy saving technologies. The empirical model used in this context is in line with many other empirical studies which focus on the effects of environmental regulation on trade flows, and it allows obtaining two major achievements. The first one is that this methodology allows building an empirical model by using data for many countries and many years, while most previous empirical studies of innovation and adoption of environmental technologies have focused on a single country, or on generally defined environmental policies.

Secondly, by using a gravity equation it is possible to investigate the role of distinct demand and supply policies for supporting biofuels on the export flows of the technologies for renewable energies and energy saving. As export flows could be considered as a measure of the competition strength at the international level (in the form of comparative advantages), thus the gravity model allows understanding if support to biofuels has been depressing competitiveness of new energy technologies.

If the effects related to public support policies devoted to biofuels will divert investments and reduce competitiveness of energy saving and renewable energy technologies, this could imply a noticeable conflict between policy actions, especially for the European Union.

On 23 January 2008 the European Commission put forth an integrated proposal for Climate Action, including a directive that sets an overall binding target for the European Union of 20% renewable energy by 2020 and a 10% minimum target for the market share of biofuels by 2020, to be observed by all Member States. Moreover, the Commission declares that further efforts to improve energy efficiency are required, reducing up to 2020 energy consumption by 20%. As stated in the document, the EU goal of saving 20% of energy consumption by 2020 through energy efficiency is a crucial part of the European energy and climate policy, because it is one of the key ways in which CO_2 emission savings can be realised. This is a clear example of a multiple set of policies which could bring to conflicting goals.

At this purpose, several alternative policy variables for public support to biofuels have been tested to underline which policies have the major impacts on the technology path, separating fuel mandates, excise tax reductions and tariffs on import flows with specific data on bioethanol and biodiesel. A further complex policy variable has been calculated by aggregating all the policy instruments for bioethanol and biodiesel separately and more generally for biofuels.

The rest of the paper is structured as follows: Section 2 gives a general overview of the biofuels sector, focusing on support policies for production and consumption; Section 3 sketches the main issues in the empirical analysis of environmental regulation and technological innovation, providing some details on gravity equation models; Section 4 describes the dataset and the methodology used whereas in Section 5, the main empirical results are reported. Section 6 concludes giving some policy recommendations.

2. OVERVIEW OF BIOFUELS SECTOR: PRODUCTION, CONSUMPTION AND POLICY SUPPORTS

Due to high oil prices together with the need to reduce GHG emission, biofuels for transport as ethanol and biodiesel have gained relevance in many countries. Bioenergy is often considered to play a key role in the short run among renewable energy sources to reduce emissions, and in this context biofuels are the only suitable substitute for fossil fuels in the transportation sector. Transportation consumes 30% of the global energy, 99% of which is supplied by petroleum (EIA, 2007) and is expected to account for about one-half of the total projected increase in global oil use between 2003 and 2030 (EIA, 2007). Global production of biofuels amounted to 9.8 EJ in 2005, about 1% of total fuel consumption in transportation but production is increasing at high rates with projection of market shares around 13% in 2050 as well manufacturing capacity (IEA, 2007). However this process has not occurred only in response to market forces but has been highly supported by government policies. Major producers of ethanol are United States with 24.6 billion litres in 2007, followed by Brazil with 19 billion lt, with the two countries representing more than 87% of world supply. Ethanol is produced respectively from corn in the US and from sugar cane in Brazil. Ethanol production in the EU is still limited (2.1 billion lt in 2007) but is growing very fast and it represent 18.5% of EU biofuels production. Main European countries in ethanol production are Spain, France, Germany, Sweden and – between new accession countries - Poland. In Europe main feedstock in ethanol production are cereals other than corn and sugar beet. Ethanol production is growing also in other countries as India and China. The EU is a leader in the production of biodiesel that is obtained mainly by rapeseed, sunflower and soybean. EU biodiesel production amounted to 4.9 millions tons in 2006 and it is localized for one half in Germany. In the last few years biodiesel production is increasing also in the US.

Biofuel production costs vary significantly across main producing countries with Brazil showing high competitive advantages. As matter of fact Brazil is the only country where at the present state of technology ethanol production can compete with fossil fuels. This is the main reason why all other producing countries adopt some forms of policy intervention.

Policy instruments regarding biofuels belong to the sphere of energy policy, environmental policy, agricultural policy and fiscal policy according to the determinants of the interest towards biofuels production and consumption in each country.

Policy instruments regard a quite large set of support and regulatory measures that can be adopted at national, regional or local level. They can be classified in three main groups:

- measures whose main impact is on supply;

- measures whose main impact is on demand;
- measures that impact on technology and market development

Supply side policy measures currently represent the bulk of support to biofuels (GSI, 2007) mainly through exemption or rebates of fuel taxes applied to gasoline and diesel or volumetric tax credits on one side and border protection through tariffs on the other side. Other forms of supply side intervention concern support to feedstock production.

A comparison at world level of policy incentives to ethanol production is given in table 1.

Table 1 – Country comparison of support to ethanol production (cent $/l)

Country	Production incentive	Excise reduction	Import tariff	Reduced tariff
Australia	-	28,9	28,9	none
Brazil	-	30	-	MERCOSUR
Canada	Up to 16,4	15,1	4,3	NAFTA, CAFTA, CILE
EU	-	Up to 70,9	24,1	EFTA, GSP (excluding Brazil))
Switzerland	-	57,8	27,7	EFTA, GSP(excluding Brazil))
USA	13,5 + state incentive	Up to 8,4	2,2% + 14,3	NAFTA, CBI

Source: Steenblik (2007)

Most countries producing biofuels apply a most-favoured nation (MFN) tariff that adds at least 20% to the cost of imported ethanol. Tariffs are lower in the case of biodiesel. The primary objective of border protection is to limit benefit of direct support through fiscal policy only to domestic producers. Various exceptions to MFN tariff and tariff.-rate quotas apply to countries with which free trade agreement exists.

As shown in Table 2, tariff regimes vary by product and by country determining the allocation of comparative advantages at world level.

Table 2 – Applied tariffs on biofuels in representative countries as 1/1/2006

Country	Ethanol(1)		Vegetable oils(2)	
	Applied MFN(3)	Imports value (current US$ 000)	Applied MFN(3)	Import value (current US$ 000)
Australia	5.0	2,771	4.1	16,544
Canada	13.1	20,398	1.0	7,906
Japan	11.1	212,566	6.6	71,363
Switzerland	43.4	18,514	70.0	15,213
United States	13.5	345,708	1.8	33,884
European Union	54.7	197,705	2.1	1,831,554

Notes:

(1) Tariffs on ethanol corresponds to the Applied MFN (AHS in UNCTAD-Trains) for the code 220710 in the Harmonized Standard classification (HS 1996)

(1) Tariffs for vegetable oils are computed as an average of the tariffs corresponding to the codes 120500, 150710, 151110, 151211, 151410 (HS 1996) weighted by the relative imports values.

(3) Values expressed as ad valorem equivalent (%), calculated as a weighted average of tariffs. The values represent the real tariff applied to international imports (AHS in Trains database) and not the declared Most-favored nation tariff (MFN).

Source: UNCTAD-TRAINS database

In addition to border protection, most countries support domestic production of biofuels through favourable fiscal regimes that reduce the cost differential with gasoline or diesel. In the US reduction in taxes for ethanol started in 1978. At present the Volumetric Ethanol Excise Tax Credit provides a fixed tax credit of $0.51per gallon of ethanol blended with motor gasoline (and $1.00 per gallon for biodiesel). The level of exemption does not adjust to changes in oil prices and additional state exemption might add.

Table 3 - Value of excise tax reduction at 1/1/2007 (€/lt)

Country	**Ethanol**	**Biodiesel**
Australia	0.23	0.23
Brazil	0.108	0.08
Canada (Federal)	0.066	0.264
EU		
Austria	0.015	0.028
Belgium	0.59	0.367
Check Republic		0.292
Denmark	0.03	0.03
France	0.37	0.37
Germany	0.65	0.47
Hungaria	0.10	0.34
Ireland	0.368	0.368
Italy	0.26	0.413
Lituania	0.25	0.25
Spain	0.42	0.29
Sweden	0.15	0.18
UK	0.32	0.32
Switzerland	0.45	0.47
USA	0.104	0.10-0.20

Source: GSI (2007).

The EU has not a unique fiscal regime at community level but through the biofuels directive (EU, 2003) has authorized member states to grant reductions from fuel excise taxes within limits. Tax rebates range from 0.10 to 0.65 €/lt with average around 0.30 and they can apply to certain types of biofuels or be not specific. Some countries as France and Italy have adopted a production quota system where tax rebate is granted up to a given amount of production.

Bioenergy is produced mainly from agricultural crops and crop residues whose cost of production range from 50% of total cost of production in the case of ethanol up to 90% for biodiesel. It follows that agricultural and agricultural products trade policies impact on biofuels economics. Price support coupled with deficiency payment support farmers in the US reducing the cost of biofuels feedstock. Plus, in the US a specific direct support of has been granted up to 2006 under the *Bioenergy Program* of the USDA. In the EU the biofuels sector has been supported by allowing growing biofuels crops on set-aside land and furthermore by granting an area direct payment of 45 €/ha to energy crops grown on not set-aside land.

Policies directed to increase the demand of biofuels by substituting them to traditional fossil fuels take the form of regulatory measures as targets and mandates requirements. While some of these do not discriminate among various forms of biofuels other can be specifically designed for ethanol or biodiesel.

Table 4 - Fuel target or mandate by country

	Fuel target or mandate	
Country	**Type**	**Quantity or blending share**
Australia	T	350 million liters by 2010
Canada	M	5% by 2010(ethanol)
		2% by 2012 (biodiesel)
EU	T	2% by 2005; 5.75% by 2010; 10% by 2020
Austria		M
Belgium	T	2.5% by 2005, 5.75% by 2010
Czech republic	T	3.7% by 2005, 5.75% by 2010
Estonia	T	2% by 2005, 5.75% by 2010
Finland	M	2% by 2008, 4% by 2009, 5.75% by 2010
France	M	
Greece	T	0.7% by 2005, 5.75% by 2010
Hungary	T	0.6% by 2005, 5.75% by 2010
Ireland	T	0.06% by 2005 Ireland provides tax exemption within a quota
Italy	T	1% by 2005, 2.5% by 2010
Netherlands	M	2% by 2007, gradually rising to 5.75% by 2010
Latvia	T	2% by 2005, 5.75% by 2010
Lithuania	T	2% by 2005, 5.75% by 2010
Poland	T	0.5% by 2005, 5.75% by 2010
Portugal	T	2% by 2005, 5.75% by 2010
Slovakia	M	2% by 2006, 5.75% by 2010
Slovenia	M	1.2% by 2006, gradually rising to 5% by 2010
Spain	M	3.4% by 2009, rising to 5.83% by 2010
Sweden T	3% by 2005, 5.75% by 2010	
United Kingdom	M	2.5% by 2008, 3.75% by 2009, 5% by 2010
USA	M	2.78% by volume of gasoline consumption in 2006 (4 billion gallons, or 15 GL); 7.5 billion gallons (28 GL) by 2012

Source: GSI (2007)

The most significant mandates, mainly in terms of the potential demand of biofuels, are the one adopted in the US and in the EU. Mandates have also been established in Brazil, China, India South Africa and other countries. These kinds of measures have usually a medium-term prospective and are accompanied by other measures in order to develop the market for biofuels.

The US mandate has been established under the Energy Bill in 2005 and it is known as renewable-fuel standard. It requires minimum levels of consumption of biofuels from 11.9 millions tons in 2006 up to 22.1 millions tons in 2012. This target level has almost been reached already in 2007.

In the EU the Directive EC 2003/30 on biofuels has fixed indicative targets up to 2% in 2005 and 5.75% in 2010. Actual average blend rate was below 1% in 2005 but nine Member states have fixed mandatory blending requirements shown in Table 4.

In Brazil support to ethanol production is mainly provided trough market regulations where a blending ratio of ethanol with gasoline between 20 and 25% is imposed. There are also other forms of incentives as credit provision for ethanol storage and tax incentives for flex-fuels cars whose sale has increased dramatically since their introduction. In Brazil dual plants prevail where production can easily shift from sugar to ethanol production according o market conditions.

Other policies specific to the biofuels sector regard support for distribution and use, support to capital investment and government funded programmes to support research, development and innovation. These forms of support have not been considered in the model given the difficulties linked to having a consistent data set. Also agricultural support through payments coupled to production or to land or through border protection trough high tariffs for agricultural products may enter in the total account of support to feedstock production but they have not been considered because they are not specific with regard of the final use of crops.

3. ENVIRONMENTAL REGULATION AND TECHNOLOGICAL INNOVATION

In the last three decades, many OECD countries have introduced alternative policy measures with the purpose of reducing environmental impacts of economic activity. The effects produced by these policy actions on the economic system are difficult to predict, especially on the pattern of technological innovation.

Many empirical studies have analysed the effects that environmental polices lead to innovation and competitiveness, adopting alternative hypothesis and different empirical model. Far from being exhaustive, two major strands of literature reveals useful insights: the pollution heaven hypothesis, and the Porter and van der Linde hypothesis. These hypotheses are oriented toward the investigation of the effects of environmental regulation on international competitiveness, and indirectly on a possible induced technical change. In both the two approaches there are contributions addressing for both specific economic sectors and the whole economic system.

Following the pollution haven hypothesis, by applying more lenient environmental regulations countries tend to reduce the production costs of their manufactures improving their ability to export, despite the possibility they will increase domestic pollution emissions. Thus, 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 (Antweiler *et al*., 2001; Bommer, 1999; Brock and Taylor, 2004; Copeland and Taylor, 2003, 2004; Levinson and Taylor, 2004).

Following Porter and van der Linde (1995), an opposite interpretation of the effects of environmental regulation brings to a theory of dynamic competitiveness deriving from technological innovation linked to stringent environmental standards: the compliance costs related to the introduction of severe environmental regulations should stimulate a country to increase the flows of green innovation becoming a net exporter of environmental technologies.

The origins of this intuition can be traced back to the seminal contribution made by Schumpeter (1947) who emphasized the importance of *creative response* of economies in adapting to changes in conditions and in the extensive literature on the induced-innovation hypothesis first advanced by Hicks (1932), who suggested that a change in the relative price of production factors represents an impulse to technological change directed to economize the use of the factor of production which has become relatively more expensive. Recent contributions generalized the induced innovation hypothesis with the inclusion of regulatory standards (especially in the environmental field) as inducement factors (Newell et al., 1999; Popp, 2006a, 2006b).

In this perspective, non-price environmental regulatory constraints may very well fit the inducement framework simply because they can be modelled as changing the shadow price faced by firms in emitting pollutants (Jaffe et al., 2003). However, while the inducement models provide a useful guide for the analysis of the interactions between the structure and the dynamics of relative prices and the direction of technological change, they miss the analysis of the actual availability of technological knowledge and of the mechanisms underlying the introduction of technological innovations (Dosi et al., 1988; Antonelli, 2003, 2008; Fagerberg et al., 2005).

When such aspects are considered, it clearly emerges that the introduction of a new environmental regulation may well represent a stimulus for new research because it affects market condition by opening up new profit opportunities, but also that innovation systems should be equipped with adequate scientific and technological knowledge in order for the economy to creatively respond to changes in external constraints.

The empirical studies estimating the existence of a pollution haven hypothesis have not completely succeed in finding robust support for this argument (Ederington and Minier, 2003; Harris *et al*., 2002; Jug and Mirza, 2005; Levinson and Taylor, 2004), while empirical findings of the Porter hypothesis are mainly based on specific industries rather than a broad sector or economic system (Albrecht, 1998; Murty and Kumar, 2003; Wagner, 2003, 2006).

One of the explanations for unsatisfactory results is the existence of poor indicators of both regulation and environmental innovations (Jaffe *et al*., 1995, 2003, 2005; Jaffe and Palmer, 1997). During the last decade data availability has been widely increased, thus explaining the revival of empirical studies upon the existence of specific trade paths related to environmental regulation. In order to produce valid results for the whole economy, recent contributions have adopted a gravity equation model investigating both on the pollution heaven hypothesis (Greter and de Melo, 2003; Harris *et al*., 2002; Jug and Mirza, 2005; van Beers and van den Bergh, 2003) and on the Porter and van der Linde hypothesis (Costantini and Crespi, 2008a, 2008b; Mulatu *et al*., 2004).

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

$$\ln F_{ij} = \ln G + \alpha \ln M_i + \beta \ln M_j - \theta \ln D_{ij} + \varepsilon_{ij} \qquad [1]$$

where F_{ij} is the trade 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 and/or as the population of the two partners, D_{ij} is the distance between the locations and *G* is a gravitational constant depending on the units of measurement for F_{ij}, M_i and M_j. 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 gravity equation allows representing supply and demand forces: if country *i* is the exporter, then M_i represents the total amount it is willing to supply to all customers, meanwhile M_j represents the total amount the *j-th* importing country demands. Distance acts as a counter force where the larger the distance, the higher the trade and transport costs.[1]

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).[2]

For the purpose of our analysis, we have chosen the gravity equation model provided in Costantini and Crespi (2008a), based on 20 OECD countries for the period 1996-2006. Far from being an empirical test of the existence of a pollution heaven or a Porter and var der Linde hypothesis, the present study relies on this framework because it constitutes a theoretically and statistically robust basis for analysing the impact of public policies on environmental technologies. We have adopted this approach for two main reasons. The first one is that public support policies for production and consumption of biofuels have been introduced very recently, never before the year 2000. By applying a gravity equation it is possible to have a wide dataset with a sufficient number of observation, thus gaining statistical robustness of our covariates related to biofuels policies.

Secondly, the final scope of our paper is to draw some policy advice related to the capacity of environmental policies (specifically for biofuels in this case) to reinforce international competitiveness, as claimed by the recent revision of the Lisbon Agenda for the EU, where sustainability goals have been addressed as an example of win-win policies, producing environmental protection and economic development. If the effects related to public support policies devoted to biofuels will divert investments and reduce competitiveness of energy saving and renewable energy technologies, this could imply a noticeable conflict between policy actions, especially for the European Union.

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, the United

[1] Four points 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.

[2] For further reading s on theoretical issues related to the gravity equation, see Costantini and Crespi (2008a).

Kingdom and the United States. The sample for *j* countries includes 148 countries (including OECD countries), and the time period analysed goes from 1996 to 2006.

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

$$\mathbf{ENEXP}_{ijt} = \alpha + \beta_1 \mathbf{GRAV}_{ijt} + \beta_2 \mathbf{ENV}_{ijt} + \beta_3 \mathbf{BIOF}_{it} + \varepsilon_{ij} \quad [2]$$

The vector of dependent variables collects the bilateral export flows from country *i* to country *j* at time *t* of three different aggregations all expressed in terms of 2000 constant PPP international US$: i) technologies for renewable energies RENWEXP_{ijt}; ii) technologies for energy saving ENSAVEXP_{ijt}; iii) the sum of the two previous variables RENWSAVEXP_{ijt}. All data for the export flows are extracted from COMTRADE database (UNCTAD) based on the Harmonized Commodity Description and Coding System (HS 1996). The typologies of technologies for renewable energies and energy efficiency - excluding all technologies for the production of bioenergies obviously - are defined by OECD (Steenblik, 2005a, 2005b) starting from the classification HS 1996. The list proposed by OECD includes all processes and products with the principal purpose of environmental protection, in order to respond to the necessity of an internationally valid definition of "Environmental goods and services" useful in the World Trade Organization negotiations. The exact definition of these kind of goods is functional to those partners asking for a specific negotiation agreement faster than the others, in order to obtained consistent tariffs reduction. In this paper, we have restricted the sample by only covering technologies for the energy sector (Table 5), thus we have merged the classification proposed by Steenblik (2005a, 2005b) with a specific study on environmental technologies provided by the Italian Research Institute for New Technologies, Energy and the Environment (ENEA, 2007). This methodological choice strictly derived from the specific purpose of this study where we investigate the role of biofuels public support in diverting the export dynamics and the technological patterns of renewable energies and energy saving technologies.

Table 5 - Technologies for renewable energies and energy savings, HS 1996

Code	Description
	Renewable energies
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 fitted with a measuring device or not; [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 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: ENEA (2007) and Steenblik (2005a, 2005b).

The general dependent variable has been split into two components, renewable energies and energy saving, in order to better understand in which specific field, if any, biofuels policies have the greater impact.

The variables included as independent covariates are aggregated into five groups as reported in Table 6. This choice is functional for the interpretation of the econometric results focusing on different aspects of our framework evaluating the role of all the drivers here considered separately and all together.

Table 6 – Definition of variables

Variable*	Definition	Source
	Dependent variables	
$RENWSAVEXP_{ijt}$	Total bilateral export flows in renewable energies and energy saving technologies (at constant 2000$ PPP) (HS definition Table A2) of countries *i* and *j*	UNCTAD-COMTRADE
$RENWEXP_{ijt}$	Bilateral export flows in renewable energies technologies (at constant 2000$ PPP) (HS definition Table A2) of countries *i* and *j*	
$ENSAVEXP_{ijt}$	Bilateral export flows in energy saving technologies (at constant 2000$ PPP) (HS definition Table A2) of countries *i* and *j*	
	Standard gravity (GRAV)	
$GDP_{i,j,t}$	Natural logarithm of GDP (constant 2000 US$) of country *i* and *j*	World Bank WDI
$POP_{i,j,t}$	Natural logarithm of total population of country *i* and *j*	
$LAND_j$	Natural logarithm of land area of country *j* (sq. km)	
$GEODIST_{ij}$	Bilateral geographic distances (CEPII calculation, Mayer and Zignago, 2006)	CEPII
COL_{ij}	Existence of colonial relationships between country *i* and *j* (dummy variable)	

$CONT_{ij}$	Geographic contiguity between country *i* and *j* (dummy variable)	
	Environmental regulation (ENV)	
$CO2_{i,j,t}$	Natural logarithm of CO_2 emission (kg per 2000 PPP $ of GDP) of country *i* and *j*	World Bank WDI
$PACE_{it}$	Current environmental protection expenditure (public+industry) as % of GDP	OECD
$ENVTAX_{it}$	Revenues from environmental taxes as % of GDP	
$ENVRD_{it}$	Public Environmental R&D as % of Total R&D	
$ENVREG_{it}$	Sum of environmental regulation policies $PACE_{it}$+$ENVTAX_{it}$+$ENVRD_{it}$ (%)	
	Support policies for biofuels (BIOF)	
$AHSBF_{it}$	Applied MFN tariff ad valorem for biofuels,[1] weighted with import flows (%)	UNCTAD-TRAINS
$AHSET_{it}$	Applied MFN tariff ad valorem for ethanol,[2] weighted with import flows (%)	
$AHSBD_{it}$	Applied MFN tariff ad valorem for biodiesel,[3] weighted with import flows (%)	
$MANDBF_{it}$	Fuel Mandate, targets of blending shares of total consumption (%)	GSI
$EXCBF_{it}$	Arithmetic mean of EXCET and EXCBD (US$ per litre of biofuels)	
$EXCET_{it}$	Value of excise tax reductions for Ethanol or ETBE (US$ per litre of pure ethanol equivalent)	
$EXCBD_{it}$	Value of excise tax reductions for Biodiesel or pure plant oil (US$ per litre of pure biodiesel equivalent)	
$TAXBF_{it}$	Arithmetic mean of TAXET and TAXBD (%)	
$TAXET_{it}$	Share of excise tax reduction for ethanol on total excise tax on gasoline (%)	
$TAXBD_{it}$	Share of excise tax reduction for biodiesel on total excise tax on diesel (%)	
$POLICYBF_{it}$	Arithmetic mean of AHSBF, MANDBF, and TAXBF (%)	

Notes:
(*) Symbols for the identification of countries and time period must be interpreted as follows:
ijt represents the bilateral interaction between exporting and importing countries with a temporal dimension.
ij represents the bilateral interaction between exporting and importing countries without a temporal dimension.
i,j,t represents the value of the variable for country i and j respectively, with a temporal dimension.
it represents the value of the variable for country i with a temporal dimension.
jt represents the value of the variable for country j with a temporal dimension.
(1) Average weighted tariff for codes (HS 1996): 2207.10 (Ethanol), 2905.11 (Methanol), 1205.00 (Rape or colza seeds, whether or not broken), 1507.10 (Crude oil, whether or not degummed), 1511.10 (Crude oil), 1512.11 (Crude oil), 1514.10 (Crude oil).
(2) Average weighted tariff for codes (HS 1996): 220710 (Ethanol), 290511 (Methanol).
(3) Average weighted tariffs for codes (HS 1996): 120500 (Rape or colza seeds, whether or not broken), 150710 (Crude oil, whether or not degummed), 151110 (Crude oil), 151211 (Crude oil), 151410 (Crude oil)

The first group (*GRAV*) collects the variables included in a standard gravity equation model. Income (GDP) and population (POP) for countries *i* and *j* allow addressing for the role of the mass of the trading partners (both exporters and importers), while geographic variables refers to the bilateral geographic distances (GEODIST) between the trading partners following the calculations provided by CEPII (Mayer and Zignago, 2006), and the total land area as a dimensional variable (LAND). In addiction, we have tested the role of two dummy variables: the existence of past colonial relationships (COL) assuming value 1 if there were colonial relationship, and the geographic contiguity (CONT) assuming value 1 if the two trading partners are neighbouring.[3]

The second group refers to alternative measures of environmental regulation (*ENV*) represented by a set of indicators, in order to generally investigate the role of regulation in environmental fields as a driver of international competitive advantages, but also to make some reflections upon the different impacts related to alternative policy measures. The first index is the current environmental protection expenditures, both of the public and the private sectors (PACE) as percentage of GDP, chosen by other recent contributions (see Costantini and Crespi, 2008a, 2008b; Hascic et al., 2008) as the best proxy for representing the environmental regulation strength.[4] The second variable is the share of environmental tax revenues on GDP (ENVTAX) and, finally, the third index is the public investments in R&D on environmental protection as percentage of total R&D expenditures (ENVRD). A synthetic measure of environmental regulation (ENVREG) is the sum of the three environmental regulation policies previously described. All these measures of environmental regulation are taken from OECD National Accounts Statistics and they have been tested separately in order to reinforce the robustness of the empirical results.

In particular, the first two indices (PACE and ENVTAX) represent a sort of market-based instruments quantification in monetary terms, while the third one (ENVRD) represent the role of public support in the environmental innovation field.

In order to test our model accounting for the role of environmental policy adopted in the importing countries, we have adopted an indirect measure of environmental stringency as the level of CO_2 emission (expressed as kg per unit of GDP at 2000 constant PPP international $). Considering that developing countries (the great part of the 148 importing 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 of renewable energies, thus indirectly revealing that they are adopting environmental regulation policies.

The third dimension is related specifically to public support devoted to the biofuels sector. As we have seen in par. 2, there a vast range of public policies which could be complementary or substitute. In this work we have considered some specific policy measures

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[3] In this paper we have adopted simple distances as a distance measure, for which only one city is necessary to calculate international distances. 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 its official capital (Mayer and Zignago, 2006).

[4] In this paper the dataset has been substantially improved comparing to the previous contributions (Costantini and Crespi, 2008a, 200b) because we have used data from OECD and not from EUROSTAT, thus covering the whole country sample with environmental regulation measures.

chosen with two criteria: the policy actions should be implemented in the whole sample of exporting countries, thus reducing possible biases in the estimation results coming from lack of data; the policy measures should be attributed from a easily recognizable starting date. Therefore, we have modelled three types of public support policies:

1) Tariffs imposed on international imports flows of biofuels, divided into ethanol and vegetable oils (raw materials for biodiesel) are from UNCTAD-TRAINS database, all expressed in terms of MFN applied duties in *ad valorem* equivalent. We have taken the MFN applied tariffs and not the bind duties in order to reduce the biases related to the possibility that bind tariffs for protected sectors are inflated for the sake of advantages in the WTO negotiations process.[5] Three variables represent this policy, referring specifically to ethanol and vegetable oils (AHSET and AHSBD, respectively) and to biofuels in general (AHSBF). All tariffs are calculated as weighted averages of the *ad valorem* equivalent with the corresponding trade flow.

2) Fuel mandates (MANDBF) expressed as a percentage target relative to the specific corresponding fossil fuels (gasoline for ethanol and diesel for biodiesel). In this case we have considered only one policy measure related to all biofuels (expressed as a simple average of the mandates in case of two separate targets) because differences between ethanol and biodiesel are minimal.

3) Excise tax reductions favouring bioethanol and biodiesel consumption. In this case we have taken the values of tax reduction (US$ per litre) for ethanol (EXCET), biodiesel (EXCBD), and globally for biofuels (EXCBF). We also computed the share of excise tax reduction on total excise tax for the two biofuels separately (TAXET and TAXBD) and generally for biofuels (TAXBF), for the purpose of homogenising the unit value (%) of this specific policy action with the others. Data for this policy measure and for fuel mandates are provided by the International Institute for Sustainable Development's Global Subsidies Initiative (GSI).

4) Lastly, we have built a synthetic policy measure (POLICYBF) in order to assess more generally the impact of biofuels public support on the competitive advantages of the other clean energy technologies. Our variable results from the arithmetic mean of AHSBF, MANDBF and TAXBF, all expressed in percentage terms.

[5] The so-called phenomenon of the "water in tariffs" corresponds to a wide range between bind duties (those declared to WTO) and applied duties (faced by importing countries in the international trade). For further details, see Bouët *et al*. (2008).

5. EMPIRICAL RESULTS

As for previous empirical studies, the gravity equation model is a good framework of analysis to test the effects of environmental policies in driving the rate and direction of competitiveness in the energy sector. Table 7 reports the results for a standard gravity equation model[6]augmented with environmental policy variables. In this analysis the market dimension of the exporting country seems to be a more incisive driver of export dynamics rather than the dimension of the receiving market. Also the variables related to the proximity of trading countries play a significant role.

Moreover, the results show that environmental regulation have an impact on the export flows in renewable energy and energy saving technologies. The coefficients associated to all the proxies of environmental stringency are statistically significant, and with the expected (positive) sign. This confirms for the sample including all countries results obtained in previous studies which considered measures of environmental regulation just for European countries (Costantini and Crespi, 2008a,b).

In the last two columns of Table 7 are presented the results related to two regressions run on more specific dependent variables such as, respectively, the bilateral export flows in renewable energy technologies (RENWEXP) and the bilateral export flows in energy saving technologies (ENSAVEXP). Again, the stringency of environmental regulation plays a role in shaping the export dynamics of such technologies, in particular for those related to energy saving objectives.

It is worth noticing that PACE and ENVTAX - the variables representing market-oriented policy measures – present higher coefficient than the public support to R&D (non reported in Table 7) and the global environmental regulation measure (ENVREG). This result confirms that there is an increasing necessity to investigate the real effect of alternative environmental regulation policies on the market, and this could be an interesting future research task.

Table 7 - The role of environmental regulation

Dependent variable	Renewable energies and Energy saving technologies (RENWSAVEXP)				Energy saving technologies (SAVEXP)	Renewable energies technologies (RENWEXP)
	CO2	PACE	ENVTAX	ENVREG	PACE	PACE
GDPj	0.012	0.056*	0.024	-0.007	0.021	0.153***
	(0.38)	(1.84)	(0.78)	(-0.22)	(0.65)	(3.77)
GDPi	1.76***	1.47***	2.414***	2.24***	1.52***	1.01***
	(30.29)	(25.05)	(40.94)	(37.31)	(24.60)	(12.26)

[6] Only Fixed Effects estimates are reported in tables. The significance of the statistics associated with the Hausman test in fact gives us indications that country individual effects are relevant in this kind of analysis so that Fixed Effect estimates are the proper technique to be applied.

POPj	-.103**	-0.11***	-0.099**	-0.100**	-0.086*	-0.125**
	(-2.35)	(-2.50)	(-2.31)	(-2.32)	(-1.88)	(-2.25)
POPi	-0.724***	-0.51***	-1.19***	-1.14***	-0.569***	0.28
	(-12.40)	(-8.77)	(-20.47)	(-19.12)	(-9.22)	(0.34)
GEODIST	-1.530***	-1.55***	-1.437***	-1.52***	-1.59***	-1.39***
	(-74.52)	(-79.34)	(-73.46)	(-77.58)	(-77.92)	(-56.65)
COL	1.34***	1.50***	1.34***	1.42***	1.47***	1.28***
	(27.34)	(30.57)	(28.01)	(29.21)	(29.30)	(21.79)
CONT	-0.28***	-0.39***	-0.109	-0.294***	-0.350***	0.076
	(-3.61)	(-5.06)	(-1.44)	(-3.82)	(-4.42)	(0.84)
LANDj	-0.553***	-0.55***	-0.55***	-0.556***	0.31***	0.333***
	(-23.09)	(-23.05)	(-23.71)	(-23.49)	(11.20)	(7.27)
CO2j	-0.11***	-0.135***	-0.127***	-0.110***	-0.084**	-0.170***
	(-2.65)	(-3.29)	(-3.13)	(-2.68)	(-1.93)	(-2.92)
CO2i	-0.317***					
	(-9.54)					
PACEi		0.523***			0.553***	0.061**
		(22.87)			(23.09)	(2.03)
ENVTAXi			0.550***			
			(37.13)			
ENVREGi				0.183***		
				(25.75)		
Adjusted R2	0.69	0.70	0.71	0.70	0.68	0.58
Obs	24569	24569	24569	24569	24569	19232

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

After having assessed the general impact of environmental regulation, the empirical analysis continues with the introduction of a number of variables considering policy measures in favour of production and diffusion of biofuels. Columns 1-3 of Table 8 show the results for the models testing the impact of tariffs *ad valorem* for biofuels on the general competitiveness in exporting energy technologies which is negative and significant, suggesting a relevant influence of such policy measures on the *direction* of technological change in the energy sector.

Table 8 - The role of policies for biofuels

Dependent variable	**RENWSAV-EXP**							**ENSAV-EXP**	**RENW-EXP**
Biofuels policy	**AHSBF**	**AHSET**	**AHSBD**	**TAXBF**	**TAXET**	**TAXBD**	**POLICYBF**	**POLICYBF**	**POLICYBF**
GDPj	0.049*	0.053*	0.051*	0.113***	0.083***	0.075**	0.074**	0.044	0.150***
	(1.59)	(1.73)	(1.65)	(3.65)	(2.73)	(2.42)	(2.43)	(1.38)	(3.68)
GDPi	1.515***	1.47***	1.641***	1.92***	1.94***	1.565***	1.82***	1.98***	0.94***
	(25.58)	(24.86)	(26.95)	(29.70)	(30.87)	(25.15)	(28.92)	(30.04)	(10.54)
POPj	-0.109***	-0.109***	-0.108***	-0.112***	-0.109***	-0.110***	-0.111***	-0.089**	-0.124**
	(-2.51)	(-2.50)	(-2.50)	(-2.59)	(-2.54)	(-2.54)	(-2.57)	(-1.97)	(-2.23)
POPi	-0.562***	-0.507***	-0.703***	-0.920***	-0.900***	-0.604***	-0.851***	-1.018***	-0.099
	(-9.49)	(-8.62)	(-11.46)	(-14.48)	(-14.67)	(-9.74)	(-13.59)	(-15.51)	(-1.12)

GEODIST	-1.54***	-1.55***	-1.55***	-1.53***	-1.50***	-1.56***	-1.51***	-1.54***	-1.398***
	(-78.04)	(-76.64)	(-79.53)	(-78.85)	(-76.71)	(-79.49)	(-76.98)	(-75.43)	(-56.43)
COL	1.49***	1.49***	1.49***	1.48***	1.47***	1.49***	1.47***	1.44***	1.28***
	(30.46)	(30.45)	(30.40)	(30.30)	(30.27)	(30.52)	(30.19)	(28.92)	(21.86)
CONT	-0.371***	-0.388***	-0.381***	-0.364***	-0.325***	-0.394***	-0.334***	-0.280***	0.065
	(-4.81)	(-5.02)	(-4.95)	(-4.75)	(-4.25)	(-5.12)	(-4.35)	(-3.56)	(0.72)
LANDj	-0.55***	-0.55***	-0.548***	-0.54***	-0.547***	-0.545***	-0.545***	0.305***	0.333***
	(-23.08)	(-23.08)	(-23.11)	(-22.98)	(-23.22)	(-22.97)	(-23.07)	(11.08)	(7.28)
CO2j	-0.130***	-0.135***	-0.134***	-0.180***	-0.163***	-0.149***	-0.152***	-0.110***	-0.166***
	(-3.17)	(-3.28)	(-3.27)	(-4.40)	(-4.00)	(-3.61)	(-3.72)	(-2.56)	(-2.85)
CO2i									
PACEi	0.518***	0.523***	0.538***	0.490***	0.517***	0.510***	0.494***	0.515***	0.066**
	(22.67)	(22.87)	(23.55)	(21.51)	(22.78)	(22.14)	(21.65)	(21.57)	(2.21)
AHSBFi	-0.002***								
	(-6.00)								
AHSETi		-0.001*							
		(-1.47)							
AHSBDi			-0.007***						
			(-10.41)						
TAXBFi				-0.008***					
				(-16.22)					
TAXETi					-0.007***				
					(-20.12)				
TAXBDi						-0.002***			
						(-4.44)			
POLICYBFi							-0.005***	-0.006***	0.001***
							(-15.05)	(-18.93)	(2.15)
Adj. R2	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.69	0.70
Obs	24569	24395	24569	24569	24569	24569	24569	23706	19232

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

The same result holds when the share of excise tax reduction for biofuels is considered (Columns 4-6), since the values of such variables increase as the incentives to the production and consumption of biofuels increase as well. We have also constructed and test the influence of a synthetic variable related to policies for biofuels (POLICYBF) which considers tariffs, fuel mandate and excise tax reduction which significantly enter in the model estimated, and with the expected (negative) sign. Finally, we have used this last variable to assess the impact of policy incentives to biofuels on the export capacity of nations in the field of energy technologies. Interestingly, such an impact appears to be negative for the case of energy saving technologies an positive for the case of renewables.

6. CONCLUSIONS

In this paper we have tested an empirical model based on a gravity equation in order to provide evidence of the negative impact produced by the public policies supporting the

biofuels sector on the export capacity of selected industrialized countries for renewable energies (excluding biofuels) and energy saving technologies.
By applying a gravity equation model on a very specific definition of energy technologies, what strongly emerges from our findings is a clear indication that pervasive public policies are detrimental to the investments and competitiveness of the new energy technologies.
As well as countries with stringent environmental standards present higher comparative advantages in the international markets of energy technologies, the introduction of public support to the biofuels sector is strongly detrimental to international competitiveness.
Results from first estimates clearly show that such policies are responsive for negative effects especially in the energy saving technologies sector. This confirms our research hypothesis, drawing some doubts on the win-win effects related to policies implemented by many industrialized economies, and particularly the EU, concerning biofuels production and consumption support.
If the stable increasing of crude oil prices recently experienced could be a clear market signal of the growing convenience of alternative energies, by subsidizing production and consumption of biofuels advanced economies produce a new distortion in the energy markets.
The policy advice of this analysis is a strong warning on public policies which will be difficult to be removed in the future continuing to distort energy markets, rather than achieving competitiveness and security of energy supply. Recalling the Lisbon Strategy and the necessity to improve a European knowledge-based society, the current policy orientation in this specific sector seems to be hardly conflicting with a possible win-win outcome.

REFERENCES

Ahmad, S., 1996, On the theory of induced innovation, *Economic Journal* 76 (302), 344–357.

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.

Antonelli, C.,2003, *The economics of innovation, new technologies and structural change*, London, Routledge.

Antonelli, C., 2008, *The path dependent complexity of localized technological change: ingredients, governance and processes*, London, Routledge, forthcoming.

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.

Binswanger, H. P., 1978, The microeconomics of induced technical change. In: Binswanger, Hans P., Ruttan, Vernon W. (Eds.), *Induced Innovation: Technology, Institutions, and Development*. John Hopkins University Press, Baltimore, MD, pp. 91–127.

Bommer, R., 1999, Environmental Policy and Industrial Competitiveness: The Pollution-Haven Hypothesis Reconsidered, *Review of International Economics*, Vol. 7 (2), pp. 342-355.

Bouët, A., Decreux, Y., Fontagné, L., Jean, S., Laborde, D., 2008, Assessing Applied Protection across the World, *Review of International Economics*, forthcoming, (doi:10.1111/j.1467-9396.2008.00753.x).

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., 2005, Economics of technological change and the natural environment: How effective are innovations as a remedy for resource scarcity?, *Ecological Economics*, Vol. 54 (2-3), pp. 148-163.

Brock, W.A., Taylor, M.S., 2005. Economic Growth and the Environment: A Review of Theory and Empirics, in Aghion P. and Durlauf, S. (eds.), Handbook of Economic Growth, Ed. 1, Vol. 1, Ch. 28, pp. 1749-1821, Elsevier.

Brunnermeier, S.B., Cohen, M.A., 2003, Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management*, n. 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.

Costantini, V., Crespi, F., 2008a, Environmental regulation and the export dynamics of energy technologies, *Ecological Economics*, n. 66, pp. 447-460.

Costantini, V., Crespi, F., 2008b, Environmental policies and the trade of energy technologies in Europe, *International Journal of Global Environmental Issues*, in press.

Dasgupta, S., Hamilton, K., Pandey, K., Wheeler, D., 2006, Environment During Growth: Accounting for Governance and Vulnerability, *World Development*, Vol. 34 (9), pp. 1597-1611.

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.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L., 1988, *Technical Change and Economic Theory*, London, Pinter.

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.
ENEA, 2007, *Energy and Environment Report 2006*, ENEA Editions, Rome (Italian version).
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.
EUROSTAT, 2007, *Energy, transport and environment indicators*, Eurostat Pocketbooks, Luxemburg, Eurostat.
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.
Fagerberg, J., Mowery, D., Nelson, R., (Eds.), 2005, *The Oxford Handbook of Innovation*, Oxford, Oxford University Press.
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.
Fisher, C., Parry, I.W.H., Pizer, W.A., 2003, Instrument choice for environmental protection when environmental protection is endogenous. *Journal of Environmental Economics and Management* Vol. 45 (3), pp. 523–545.
Grether, J.-M., De Melo, J., 2003, Globalization and Dirty Industries: Do Pollution Havens Matter?, *NBER Working Paper* n. 9776, Cambridge, MA, USA.
GSI, 2007, *Biofuels – At What Cost? Government support for ethanol and biodiesel in the selected OECD Countries*, Global Subsidies Initiative, International Institute for Sustainable Development, www.globalsubsidies.org.
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.
Hicks, J. R., 1932, *The Theory of Wages*, London, Macmillan.
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.
IEA, 2007, World Energy Outlook 2007, Paris.
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., 2003. Technological change and the environment, in Mäler K.G., Vincent, J.R., (eds.), Handbook of Environmental Economics, edition 1, volume 1, chapter 11, pages 461-516, Elsevier.
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.
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.
Milliman, Scott R., Prince, Raymond, 1989. Firm incentives to promote technological change in pollution control. *Journal of Environmental Economics and Management* Vol. 17, 247–265.

Mulatu, A., Florax, R., Withagen, C., 2004. Environmental Regulation and International Trade: Empirical Results for Germany, the Netherlands and the US, 1977-1992, *Contributions to Economic Analysis & Policy*, Berkeley Electronic Press, vol. 3 (2), pages 1276-1276.
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.
OECD, 2005, *Agricultural Market impacts of the future growth in the production of biofuels*, OECD, Doc AGR/CA/APM(2005)24/Final, Paris,
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., 2006a, International innovation and diffusion of air pollution control technologies: the effects of NO_X and SO_2 regulation in the US, Japan, and Germany, *Journal of Environmental Economics and Management*, Vol. 51 (1), pp. 46-71.
Popp, D., 2006b, Innovation in climate policy models: Implementing lessons from economics of R&D, *Energy Economics*, Vol. 28 (5-6), pp. 596-609.
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., 2005a, Environmental goods: A comparison of the APEC and the OECD lists, *OECD Trade and Environment Working Paper* n. 2005-04, OECD, Paris.
Steenblik, R., 2005b, 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.
Tokgoz S., Elobeid A., Fabiosa J.,. Hayes D. J, Babcock B., ,Tun-Hsiang A., Yu E., Dong F., Hart C. E,,. Beghin J.C, 2007, Long-Term and Global Tradeoffs between Bio-Energy, Feed, and Food, Center for Agricultural and Rural Development, Iowa State University, *Selected Paper* American Agricultural Economics Association Annual Meeting, Portland, OR, July 29–August 1.
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., 2003, Environmental regulation impacts on international trade: aggregate and sectoral analyses with a bilateral trade flow model, *International Journal of Global Environmental Issues,* Vol. 3 (1), pp. 14-29.
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*, Working Paper, Centre for Sustainability Management, Univesitat Luneburg, Germany.
Wagner, M., 2006, A Comparative Analysis of Theoretical Reasoning and Empirical Studies on the Porter Hypothesis and the Role of Innovation, *Zeitschrift für Umweltrecht und Umweltpolitik*, n. 3, pp. 349-368.
Wheeler, D., 2001, Racing to the Bottom? Foreign Investment and Air Pollution in Developing Countries, *Journal of Environment and Developmen*t, Vol. 10 (3), pp. 225-245.
World Bank, 2006, *World Development Indicators (WDI)*, on-line database, The World Bank, Washington DC.