THE IMPACT OF ENVIRONMENTAL EFFICIENCY ON BILATERAL TRADE: A PANEL DATA ESTIMATION OF GRAVITY MODEL

A Master's Thesis

by

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January 2009

To My Family

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ON BILATERAL TRADE: A PANEL DATA
ESTIMATION OF GRAVITY MODEL

The Institute of Economics and Social Sciences
of
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by

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January 2009

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ABSTRACT

THE IMPACT OF ENVIRONMENTAL EFFICIENCY
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In this study the role of environmental efficiency in the determination of bilateral trade flows is empirically examined by using Gravity Model for a panel data for 1971 to 2003. Although there are a number of empirical studies that analyze the relationship between environment and trade, most of them show insignificant relationship between environmental regulations and trade. Their differences are mostly due to the use of stringency indicators that are computed with different methods. This study, unlike previous studies, computes the environmental efficiency as a hyperbolic measure of technical efficiency in a non-parametric piecewise linear technology, with a production plan that maximizes the desirable outputs while simultaneously minimizing the resource use and pollution emission. The relationship between bilateral exports and environmental conditions measured as environmental efficiency index is investigated. The empirical results indicate that although there is no significant relationship between exports of a country and its own environmental efficiency index, there is a strong and robust positive effect of the partner country's environmental efficiency index.
Keywords: Environmental Efficiency Index, Gravity Model

ÖZET

ÇEVRESEL ETKİNLİĞİN KARŞILIKLI TİCARETTE ROLÜ:
ÇEKİM MODELLERİNİN PANEL ANALİZİ

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Bu tezde, Çekim Model kullanılarak karşılıklı ticarette çevresel etkinliğin rolü, 1971 2003 yılları arası panel analiz yapılarak amprik olarak incelenmiştir. Literatürde, her ne kadar çevre ile ticaret arasındaki ilişkiyi araştıran çok farklı çalışmalara rastlamak mümkün olsa da, ampirik çalışmaların çoğunda çevre mevzuatı ile ticaret arasında zayıf yönlü bir ilişki kurulduğu görülmüştür. Bu tezde, diğer çalışmaların aksine, çevresel etkinlik "non parametrik parçalı linear" teknolojideki teknik etkinliğin hiperbolik bir ölçümü olarak hesaplanmıştır. Bu methodla kaynak kullanımını ve kirliliği minimize eden aynı zamanda üretimi maksimize eden üretim planı varsayımı altında ikili ihracat ve çevresel şartlar arasındaki söz konusu ilişkiyi ölçebilmeye yarayan çevresel etkinlik endeksi bulunmuştur. Elde edilen amprik sonuçlardan, bir ülkenin ihracatı ile çevresel etkinlik endeksi arasında belirgin bir ilişki olmasa da, diğer ülkenin çevresel etkinlik endeksinde güçlü bir pozitif etkinin olduğu sonucuna ulaşılmıştır.

Anahtar Kelimeler: Çevresel Etkinlik, Çekim Modelleri

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CHAPTER I

INTRODUCTION

Human beings have made major impact on the world's ecosystems. A century ago, human use of the planet's resources was much less, and not perceived as destructive. However, today the damage can be seen in the form of global warming, air pollution, acid rains, new diseases and ecological collapse. The threat of the environmental pollution is one of the most important dangers of the world, and human activity is responsible for most of this damage. Rapid growth in industrial and agricultural production and increasing life standards are disrupting the environment and creating a threat on human beings.

Today global warming is most apparent environmental damage. According to Gillett, et al (2008) report[1] the increase in atmospheric greenhouse gases due to human activity has caused most of the observed warming since the start of the industrial era and the contribution of human activity to global

[1] Gillett, Nathan P, Dáithí A. Stone, Peter A. Stott, Toru Nozawa, Alexey Yu. Karpechko, Gabriele C. Hegerl, Michael F. Wehner & Philip D. Jones (2008). "Attribution of polar warming to human influence". Nature Geoscience 1: 750. doi:10.1038/ngeo338. http://www.cru.uea.ac.uk/~nathan/pdf/ngeo338.pdf.

warming is obvious in the last fifty years. Moreover, according to the report of Climate Change (2007): The Physical Science Basis, Intergovernmental Panel on Climate Change[2], global temperatures on both land and sea have increased by 0.75 °C (1.35 °F) relative to the period 1860--1900 and by this speed it will not be too long for human to face with flood and drought. Furthermore, global warming as its name suggests is a global issue that one country having rules that protect the environment and the others not having rules will not help to clean the environment. Hence, environmental concerns should be treated as a global issue with the involvement of all countries.

Environmental concerns are becoming a significant factor in international trade as expressed by Daniel C. Esty[3] "*Public health standards, food safety requirements, emissions limits, waste management and disposal rules, packaging and recycling regulations, and labeling policies all may shape trade flows.*" Many cases of disputes are reported to WTO regarding countries limiting their imports from trade partners that do not protect the environment properly. To illustrate, one of the dispute in WTO is tuna-dolphin case, in which the United States banned Mexican tuna imports because the fishing methods resulted in incidental dolphin deaths. Another example is European Union the

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[2] "Summary for Policymakers" Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (2007-02-05). Retrieved on 2007-02-02. "The updated hundred-year linear trend (1906 to 2005) of 0.74 °C [0.56 °C to 0.92 °C] is therefore larger than the corresponding trend for 1901 to 2000 given in the TAR of 0.6 °C [0.4 °C to 0.8 °C]."

[3] Daniel C. Esty, "Bridging the Trade-Environment Divide, "Journal of Economic Perspectives, Volume 15, Number 3 Summer 2001, Pages 113--130

ongoing beef hormone dispute. The European Union has adjusted its "no added hormones in beef" food safety standards and prefers this kind of beef in their imports. The U.S. sanctions against Thai shrimp caught using methods that killed endangered sea turtles is a further examples of trade restrictions due to environmental concerns.

In addition to these examples of overt trade limitation due to environmental concerns, another impact of environment on trade is through changes in comparative advantage. Countries with comparatively lower levels of environmental regulations have a comparative advantage in the production of pollution intensive goods. On the other hand, countries having strict regulations may prefer importing these goods instead of producing them since environmental regulations impose significant costs and thereby prohibit the ability of firms to complete in international markets. Therefore, this loss of competitiveness can be directly seen in declining exports and increasing imports.

This study aims to find whether environmental strictness has an effect on international trade flows. The claim is that countries having strict environment regulations imports goods from countries having less environment regulations. The gravity model of trade is empirically estimated using a panel data for 27 countries and for the period 1971-2003. Although there are a number of empirical studies that analyze the linkage between environment and trade, most of them find insignificant relationship between environmental regulations and trade. Their differences are mostly due to the use of different stringency indicators computed with different methods or different ranking techniques.

In this study apart from previous studies the environmental strictness conditions are measured using frontier analysis in an output framework in which outputs are treated asymmetrically. Among many input, output combinations, the producer favors the production plan that maximizes the desirable outputs while simultaneously minimizing the resource use and pollution emission. In this analysis hyperbolic measure of technical efficiency in a non-parametric piecewise linear technology that satisfies weak and strong disposability assumptions is computed. The hyperbolic distance difference between the weakly and strongly disposable technologies allows us to quantify desirable output loss due to the lack of strong disposability of undesirable outputs. This measure of environmental efficiency shows the opportunity cost of transforming the production process from one where all outputs are strongly disposable to the one which is characterized by weak disposability of undesirable outputs.[4]

This study mainly differs from previous studies in the sense that environmental efficiency index is used to measure the environmental policy performance of the countries. One of the main advantages of using environmental efficiency index computed by Data Envelopment Analysis is that the best practice frontier is estimated without making any assumption for the

[4] See Fare et al (1989(a), 1989(b)) and Zaim, Taşkın (2000) studies. Further details of the methodology are explained in Environmental Efficiency section.

shape of production function. It is an output oriented approach that can be applied to macro data and actual pollution can be included into the computations. To calculate these indices, two linear programming problems one with weakly disposable technology set of undesirable output and another one with strong disposable output sets are calculated for 27 countries for each year between 1971 and 2003[5]. Environmental efficiency index for each country is computed as the ratio of these two technical efficiency scores obtained for each year.

Gravity Model, which explains bilateral trade flows as a positive function of economies of countries (measured by GDP) and a negative function of distance between these two countries, is used as the empirical framework to illustrate the relationship between environment and trade. The study offers a review of both the theoretical[6] and empirical literature of the Gravity Model, as well as the literature that previously examined the impact of the environment on trade volumes.

The study investigates empirical relationship between trade and environmental efficiency for 27 countries for 1971-2003.[7] First, pooled Ordinary Least Squares (OLS) estimators are utilized to expose the relationship between the environmental efficiency and bilateral exports. Fixed effects are added into

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[5] In order to calculate the environmental efficiency indices, these two linear programming problems are solved by using GAMS (General Algebraic Modeling System) for every time period between 1971 and 2003.
6 See Appendix A for further details.
[7] All estimations are performed using Stata 9.0.

the model to account for the country special effects. To explain the deviations from normal trade patterns, gravity model is extended to include the effect of population, land, common language, adjacency and European Union membership variables. Furthermore, a set of robustness check are performed. Due to the possible simultaneity bias we instrument countries income level by their five year lagged values where we employ cross sectional, country fixed panel data estimators, and we put further a restriction on the equality of the coefficients of environmental efficiency index of importing and exporting countries.

In the empirical analysis, we find that there is no significant relation between the exports of a country and its own environmental efficiency whereas there is a strong and robust relationship with the environmental efficiency of the partner countries. The results indicate that the environmental efficiency of the country is positively related to its own imports. In other words, since countries are more powerful to determine the volume of their imports than their exports, their own environmental efficiency mostly affects their own purchases from other countries. Moreover, the impact of high environmental efficiency of the exporting country on its bilateral exports is not significant.

The plan of the thesis is as follows: Chapter 2 gives a literature review of the theoretical and empirical literature on Gravity model. Chapter 3 analyzes the relationship between environmental efficiency and trade, its theoretical and empirical literature. Chapter 4 describes the computation of environmental efficiency index, gives its literature, details of the data and results. Chapter 5 discusses the empirical results and finally Chapter 6 concludes.

CHAPTER II

LITERATURE REVIEW ABOUT GRAVITY MODEL OF TRADE

2.1. Theoretical Studies of Gravity Model

Gravity model is one of the most successful empirical trade models in international trade. In 1976, Jan Tinbergen first used the simple gravity model of trade in international economics. Simple gravity model explains bilateral trade flows with a framework similar to Newton's Gravity law in Physic. It says bilateral trade flows is positively related to economic sizes of two countries (measured by GDP) and negatively related to the distance between these countries. In equation form, it is expressed as:

$$Trade\,Flow_{ij} = aGDP_i.GDP_j / D_{ij}$$

where notation is as follows:

• $Trade_{ij}$ is the bilateral trade flow from country i to j.

• GDP_i and GDP_j are the gross domestic products of country i and j.

• D_{ij} is the distance between the two countries.

• a is a gravitational constant depending on the units of measurement for mass and force.

According to Deardorff (1984) "gravity models are `extremely successful empirically,' judging by their ability to explain variance in bilateral trade volumes". Moreover, Leamer and Levinsohn (1997) have written that "gravity models have produced some of the clearest and most robust empirical findings in economics."

Following Tinbergen's empirical study, the initial theory behind the gravity model has been studied by economists. Formal theoretical foundations of gravity models have been provided by Anderson (1979), and Bergstrand (1985, 1989). They also provided under certain assumptions the micro foundations of gravity model and some empirical evidence to support the gravity equation that explains trade between two regions as decreasing in transportation cost (distance) and increasing in income. Anderson is the first one to derive gravity equation under product differentials with Cobb-Douglas preferences and CES preferences. Bergstrand (1985) with CES preferences over differentiated product derived a reduced form equation for bilateral trade involving price indices. In Bergstrand (1989), the assumption of monopolistic competition model leads to model product differentials. Using a two sector economy which both is monopolistically competitive sector, a version of gravity equation is derived.

There are other theoretical trade studies that derive the gravity model with different assumptions. Like previous studies, Helpman and Krugman (1985) has derived gravity model from monopolistic competition model and

Deardorff (1995)[8] has shown that the gravity model can be derived from the classical framework of the Hecksher-Ohlin model by assuming either identical preferences or CES preferences. Moreover, Eaton and Kortum (2002) have developed a Ricardian model of trade in homogenous goods that generates a gravity-type relationship. Feenstra, Markusen and Rose (2001) estimated gravity equation in monopolistic competition model depending on whether goods are homogeneous or differentiated and whether or not there are barriers to entry.

More recently, the fit of the gravity equation has been used as a test of trade theories Harrigan (2002) reviewed the theoretical models of the gravity equation. Haveman and Hummels (2004) have found that gravity model is consistent with incomplete specialization models.

From these studies, the theory behind the gravity equation can be seen. Depending on the gravity model's theoretical explanation, there are many empirical studies that use gravity equation to explain different aspects of trade. Although, simple gravity model has a significant empirical power for trade, the model is extended to include variables such as population (or income per capita), adjacency, common language and colonial links, remoteness, border effects… to the model. In the following sub-section, the empirical studies that use gravity equation are summarized.

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[8]Since our theoretical framework is adopted from his article, in Appendix A his study is going to be summarized deeply in order to achieve the theoretical base of the gravity equation.

2.2 Empirical Applications of Gravity Model

The gravity model is one of the most successful empirical models used in explaining international trade flows. The following section offers a summary of the large number of empirical studies produced.

Prior to Tinbergen, Aitken (1973), attempts to explain European trade relation using gravity equation. He estimates the impact of the European Economic Community (EEC) and the European Free Trade Association (EFTA) on members' trade flows with a gravity model. Adding dummy variables to model, he concludes both the EEC and EFTA have an effect on growth in Gross Trade Creation (GTC) over their respective integration periods, but with the GTC of the EEC is being substantially greater than the GTC of EFTA.

Sanso, Cuairan and Sanz (1993) question the general log linearity form of gravity equation and study the possibility of a general functional form through Box-Cox transformations. Using data corresponding to the sixteen OECD most developed countries from 1964 to 1987 they reach the conclusion that the optimal functional form is slightly yet statistically, different from the log linear form.

Bandyopadhyay (1999) using bilateral trade data from twenty-three OECD countries studies the link between an economy's distribution sector and its international trade. In his paper his claim is that the usual estimation procedure for the gravity equation has ignored two problems in the literature and he suggests an estimation procedure to deal with these problems. The first problem he claims is simultaneity. Since international trade flows has a significant part of GDP, which is the one of the regressor of the gravity equation, there is a causality problem in gravity equation. Then, the OLS estimation of coefficients is inconsistent. In order to solve this problem, he uses instrumental variable technique and suggests GDP lagged five years variable which is highly correlated to the independent variable GDP and yet are independent of the error term as a possible instrument. The second problem he claims is the omission of variables that makes OLS biased. Here, using country fixed effect in a panel study specific to each pair of country that stay constant over time is suitable for solving this problem.

Grünfeld and Moxnes (2003) identify the determinants of service trade and foreign affiliate sales in a gravity model. They search links between service FDI and trade. They conclude that trade barriers and corruption in the importing country have a strong negative impact on service trade and foreign affiliate sales. They found a strong home market effect in service trade, and rich countries do not tend to import more, which may indicate that rich countries have a competitive advantage in service trade. Free trade agreements do not contribute to increased service trade.

Kim, Cho and Koo (2003) using a dynamic gravity equation, examine the nature of trade patterns among OECD countries and show that the national product differentiation model explains food and agricultural trade more properly, while the product differentiation model is more appropriate to explain large-scale manufacturing trade. A dynamic gravity equation is developed to examine the significant impact of changes in relative market size on the pattern of bilateral trade over time in both the short- and long-run. They conclude that both the short- and long-run: the national product differentiation model explains food and agricultural trade more accurately, while the product differentiation model is more appropriate to explain large-scale manufacturing trade.

Kimura and Lee (2004), using gravity equation assesses the impact of various factors on bilateral service trade and compare the explanatory variables of services trade from goods trade. They conclude that the gravity equation for services trade is as robust as the gravity equation for goods trade but there are some differences, with regard to the elasticity of the explanatory variables between services and goods trade. Most importantly they find that geographical distance is consistently more important for services trade than for goods trade. They also find that membership in the same regional trade arrangement has a significant impact on both services trade and goods trade. Another interesting result they find is that both goods trade and services trade are positively affected by economic freedom but the effect is much stronger for services trade.

Batra (2004), attempts to estimate trade potential for India using the gravity model approach. He first uses an augmented gravity model to analyze the world trade flows and the coefficients obtained are then used to predict trade potential for India. Then, the estimation results show that the gravity equation fits the data. All variables' coefficients of the traditional "gravity" effects have expected sign, with statistically significant t-statistic.

Egger (2004) studies panel gravity equation and concludes a panel framework has many advantages over the cross-section approach. First of all it allows disentangling country-specific and time-specific effects. He demonstrates by the Hausman χ^2-test that the proper econometric specification of a gravity model in most applications would be the fixed country and time effects.

Musilar (2004) uses the gravity model to examine the impact of the Common Market for Eastern and Southern Africa on the flow of Kenya's exports. His results suggest that COMESA has the effect of trade creation. No evidence for trade diversion is found. Accordingly, COMESA has helped to improve Kenya's export performance. The results also show that nominal GDP of importing countries, distance, adjacency, and common official language have a statistically significant impact on the flow of Kenya's exports.

Brun et al. (2005) examines the distance structure in bilateral trade between rich countries and poor countries by gravity model. Using panel gravity model he concludes that the estimated coefficient of distance on the volume of trade is found to increase through time. Furthermore, he divides the sample into low- and high-income countries, and finds that the elasticity of bilateral trade with respect to distance reveals no trend for low-income countries' trade, whereas it falls for bilateral trade between high-income countries.

As introduce above, gravity equation is a widely accepted model of trade flow. This study, the relationship between trade and environmental is analyzed by using the Gravity equation where environmental regulations is measured using environmental efficiency index. Before explaining the detail of this measure, the literature behind the relationship between environment and trade is summarized in following section.

CHAPTER III

THE RELATIONSHIP BETWEEN TRADE AND ENVIRONMENT

3.1. Theoretical Studies

The According to international trade theories countries engage in trade because of comparative advantage and the sources of comparative advantage differences are technology and factor endowments. In Ricardo's theorem of trade, technology is the source for comparative advantage and countries will export the goods that their technology is relatively more efficient than the other countries. In the Heckscher-Ohlin theorem, technology is assumed to be identical across countries; comparative advantage and the pattern of trade depend on relative factor endowment. In other words, differences in resources can drive trade patterns.

Differences in factor endowment and technology are the main reasons for trade. However, are environmental regulations that countries have also sources of the comparative advantage? The impact of environmental regulations on trade is frequently a debated subject that there are a number of studies that examine this relationship. However, most studies using various ways to measure environment regulation have found that there is no empirical evidence that environmental standards have an effect on trade. However, the logic behind this relationship cannot be denied that environmental regulations affect the comparative advantage: countries with comparatively lower levels of environmental regulations have a comparative advantage in the production of pollution intensive goods. Obviously, strict environmental regulations imply higher pollution disposal costs and lower natural capacity to assimilate pollution. Therefore costly environmental regulations make countries face unfair competition in the world market and the other countries with low level of environmental regulation have a comparative advantage over it.

There are theoretical studies that analyze the impact of environmental regulation on comparative advantage. Siebert (1977) which is one of the initial study that analyze the role of environmental policy on international trade, constructs a two-commodity open economy model with home country has a comparative advantage in the production of pollution intensive good. The specialization in this pollution intensive good increase the emission and environmental quality declines in home country. His claim is if a country exports its pollution-intensively produced commodity, its gains from trade are accompanied by a decline in its environmental quality. With the introduction of environmental policy, Siebert concludes that resources use in the pollution-intensive sector will decline. In other words, environmental policy makes the production of the pollution intensive commodity more costly that means environmental regulations make the volume exports decline.

Like Siebert Baumol and Oates (1989) present the same results. In their model, two countries produce an identical traded commodity. The production processes in both countries generate pollution. Under partial equilibrium conditions, Baumol and Oates argue that if a country does not develop an environmental protection program when other countries do, that country will increase its comparative advantage or decrease its comparative disadvantage in the pollution-intensive industry. It will then specialize in that industry at the cost of environmental damage.

Carraro and Siniscalco (1992) analyze the environment and competitiveness relationship in a different framework. Instead of assuming fixed emission-output ratios in which the desired emission target is reached by decreasing the output through appropriate policy instrument like Siebert (1977) or Baumol and Oates (1989), Carraro and Siniscalco consider the case in which a national government achieves the desired pollution level by inducing industrial firms to invest and innovate, in order to reduce unit emissions through changes in technology. They analyze how the new technologies required by environmental policies affect the competitiveness of pollution-intensive industries. They consider one polluting industry in an open economy where domestic firms produce only single, homogenous good and compete in the international market. Therefore, the authors assume that before the home country imposes technology standards for reducing emissions, the industry freely trades the product in the world market and all countries have identical technology. Technological innovation increases the marginal cost of the product.

Under different market structures--perfect competition, Bertrand oligopoly, Cournot oligopoly, they examine how the industry's profit changes after the home country imposes unilateral pollution control. Carraro and Siniscalco conclude that in the presence of international competition, the technical innovations required by environmental regulations will distort the industry's competitiveness and make it loose profits. Their suggestion to this loss is a government subsidy and the optimal subsidy depends on the market structure and abatement costs.

Different from Carraro and Siniscalco model that concludes differences in the strictness of environmental regulation is the reason of trade, Sartzetakis and Constantatos (1994) analyze the case that if the two open country have the same level of strictness but use different instruments to regulate environment and investigate how a country's choice of environmental policy instrument affects the international competitiveness of its firms. In the oligopolistic model, the authors show that at Cournot-Nash equilibrium the firms regulated by the tradable emission permit have a larger market share than the firms regulated by the command and control method. This is because the market-based instrument system reduces the average pollution abatement costs through permit trading. In addition to regulatory instruments, policymakers use well-defined property rights as an alternative policy to prevent environmental deterioration. Their work suggests that free trade situations should not only result in similar environmental standards but also in similar regulatory regimes.

Another important study that analyzes the relationship between environment and trade is Chichilnisky (1994). Chichilnisky uses a model similar to Heckscher-Ohlin model except that the supplies of inputs are price dependent. In the model, he assumes that like H-O model there are two countries having identical technologies, resources, and preferences. The only difference they have is the property rights laws that apply to environmental resources. Like actual world he named countries as north and south and let environmental resources to be unregulated common property in the south but private property in the north. Under these assumptions, his claim is the common-property supply curve for the resource lies below the private- property supply curve so that under common-property regimes, more is supplied at any given price. Therefore his model's reason to trade is the difference between property rights of countries. As he assumes South has unregulated common property rights, this leads it to have a comparative advantage over north. So South exports environmental intensive good. Here, Chichilnisky shows that trade makes the environment overuse. Moreover, he shows that under these assumptions, tax on the use of environmental resources may increase their use further. Therefore, he concludes that property rights policies are more effective than taxation.

3.2. Empirical Studies

In addition to theoretical literature the debate on the impact of environmental regulation on comparative advantage has generated many empirical studies. Walter (1973) performed one of the first study trying to analyze the role of environmental policy in international trade. In his paper, his aim is to determine overall environmental control of US economy that let him to compare its exports and imports abatement cost and other environmental protection activities for all sectors of the US economy. He uses an input-output model and estimate direct environment loading for each sector. He proves this way that, on average, the abatement cost content of US exports is slightly higher than that of US imports which suggests that the US is relatively well endowed with environmental resources compared to the rest of the world. However, his paper does not analyze the impact of differences in environmental regulations on international trade.

There are several studies that explicitly link the environmental regulations and international trade. However, there is no widely accepted indicator to measure the international differences in environmental regulations and the empirical studies have used different approaches to measure this difference. Furthermore, some of the earlier studies which examined the impact of environmental regulation measured with a variety of techniques fail to find significant relationship. The Organization for Economic Cooperation and Development (OECD) reported that case studies of macro-level evaluations of environmental policy of Italy, the Netherlands, Japan, and the United States are

(OECD, 1978). The method they use is similar to Walter's and their results do not show significant evidence that environmental regulations trigger a reduction in output and exports. Another study is done by Ugelow (1982) who reviews 10 empirical studies through the 1970s on the costs of environmental regulation and its effect on international trade. Ugelow reports that there is no consistent conclusion on the issues. There are industrial location studies (Leonard 1988; Pearson 1985, 1987; Walter 1982) that have found little evidence that pollution-control measures have exerted a systematic effect on international trade and investment. Even though it is difficult to compare these diverse studies, it seems that the impact of environmental regulations on international trade is less than expected.

On the other hand, some of the more recent studies which focused on the disaggregated trade flows have found significant environment effect on trade flows which varies by international market structure, industry over time. To illustrate, Kalt (1988), using an input-output model in a Heckscher-Ohlin framework, regressed changes in net exports between the years 1967 and 1977 across 78 industrial categories on changes in environmental compliance cost. He first finds statistically insignificant inverse relationship then, when he restricted the sample to manufacturing industries, he identifies the significant impact of domestic environmental policies on US international competitiveness. Moreover, the magnitude and significance of this impact can be increased even further when the chemical industry was excluded from the sample.

Like Walter (1973), Robison (1988) use input-output analysis to measure the impact of marginal changes on US balance of trade caused by industrial pollution abatement. However, he uses an ex-post partial-equilibrium framework that is different than the Walter who uses ex-ante forecasting method. Robison suggests that the pollution control content of goods imported to the United States increased at a higher rate than did the control content of exported goods. In other words, imports have higher abatement cost content than do exports. Robinson asserts that environmental regulation reduced the United States' manufacturing comparative advantage in pollution-intensive industries and caused a shift in trade patterns towards importing pollution intensive commodities. However, he concludes that marginal changes may affect trade, but the effect should be small overall.

One of the most important empirical study on trade and the environment is Tobey (1990). His method is completely different from the others. He uses a cross section Hecksher-Ohlin-Vanek (HOV) model of international trade to test the hypothesis that the strictness of environmental regulations is linearly related to the exports of polluting industries. He uses a qualitative variable to represent the stringency of pollution control in the estimation. The scale ranges from one to seven, with seven standing for the strictest regulation. He regresses the exports of dirty industries on eleven factor endowments and the strictness indicator with cross-section data from 23 countries. In his paper, he concludes that the stringent environmental regulations imposed on industries in the late

1960's and the early 1970's by most industrialized countries have not measurably affected international trade patterns in the most polluting industries.

Like Tobey, Cees van Beers and Jeroen van den Bergh (2000) analyze the relationship between trade and environment by using the same qualitative variable but use Gravity model of trade. Their improvement is the use of more disaggregates data in addition to variety of sectors. However, their results conclude that there is no significant effect of environmental regulation on trade. One of their previous study Cees van Beers and Jeroen van den Bergh (1997) again analyze the relationship between environment and trade, but in this paper they use a different stringency indicator that mainly based on output-oriented framework. Their measure is created by a ranking procedure that assigns number 1 to the worst performer, 2 to the second-worst performer for different indicators. Then, for each county these numbers are summed up and the results of this is ranked again. Finally, these outcomes are divided by the number of countries in the analysis, so that an index ranking between 0 and 1 is created. Environmental measure does not depend on a theoretical foundation and does not consider the different weights of the sectors in total exports. By using Gravity model they estimate the relationship between environment and trade but again they find an insignificant relationship between them.

To sum up, there are a large number of studies that analyze the relationship between environment and trade. Their differences are mostly due to the use of different stringency indicators. These comprise input versus outputs oriented framework, cost versus physical measures or objective versus subjective measures. Moreover, they use different trade models and data based on country, firm or plant level. However, most studies show insignificant relationships between stringent environmental regulations and trade and only some of the more recent and more focused studies have found the predicted negative effect on trade flows at a disaggregated level, but the significant effect is small and changes over time and varies by industry and market structure.

Addressing the relationship between environment and trade is fundamental in order to achieve sustainable development. Moreover, widespread use of development strategies that focus on trade liberalization and resulting pressure on environment makes this relationship more important than before. Therefore, this study aims to examine the relationship between environment and trade. The main contribution of this study is to measure environmental condition as an efficiency measurement approach and use output oriented macro data. Following section summarizes the theory and some of the previous empirical application of the environment efficiency measures.

CHAPTER IV

ENVIRONMENTAL EFFICIENCY INDEX

4.1 Literature Review

Farrell (1957) introduced measure of technical efficiency to gauge the performance of a firm. The term "efficiency" of a firm means its success in producing as large as possible output from a given set of inputs.[9] Following Farrell (1957)'s influential work, a huge literature was developed; most of the focus is on productive efficiency. The methodology is then extended to measure environmental efficiency. Since the focus of the present study is to analyze the impact of environment efficiency on trade, literature behind this efficiency analyzes is going to be summarized.

One of the earliest studies that measures environmental efficiency is by Pittman (1983) who takes pollution as an undesirable output and result in a multilateral productivity index which includes both undesirable output and desirable output measures. Pittman extended the environmental efficiency generalizing Caves, Chiristensen and Diewert (CCD) (1982a, 1982b)

[9] The basic concept of technical efficiency described by Farrell (1957) is summarized in Appendix B.

multilateral productivity index by modifying CCD model and adding measures of undesirable output as well as desirable output. As stated by Pittman (1983), the form of the index is basically a superlative productivity index that is exact for a translog transformation function like CCD model with the exception that undesirable outputs are valued by their shadow prices rather than their market prices.

More recently, Fare et al (1989(a), 1989(b)) use a non parametric approach that consider undesirable outputs like Pittman but they depart from Pittman model of CCD and modify Farrell (1957)'s work to measure efficiency. Their modification permits an asymmetric treatment of outputs, between desirable outputs and undesirable outputs. That is among many input, output combinations, they favor the production plan that maximizes the desirable outputs while simultaneously minimizing the resource use and pollution emissions. They adopt hyperbolic measure of technical efficiency in a non-parametric piecewise linear technology that satisfies weak disposability of undesirable outputs and strong disposability of other output. The difference between the weakly and strongly disposable technologies enables them to quantify desirable output loss due to the lack of strong disposability of undesirable outputs. The theory behind this approach is going to be summarized in order to achieve the theoretical base of the derivation of environmental efficiency measure. Alternatively, Tyteca (1997) computes an environmental performance indicator based on the decomposition of factor productivity into pollution index with an application to data from US fossil fuel-fired electric utilities.

Under the theory of Fare et al (1989), many micro and macro level studies have been done to analyze the measure of environmental efficiency index. The use of macro data in studies that employ production frontier techniques has been applied by Zaim, Taşkın (1999) and (2000) that measure the environmental efficiency index for OECD countries. Moreover, Yörük and Zaim (2008) employs the data envelopment analysis (DEA) approach to compute the environmental performance of (OECD) countries by using distance functions approach as they scale the good and bad outputs separately. Yörük and Zaim (2006) establish an environmental Kuznets curve relationship between environmental efficiency and income. This study measure environment efficiency using macro level data account for the pollution emissions in production function. The following subsection summarizes the theoretical background for the development of the environmental efficiency index.

4.2 Model

To describe the theoretical underpinnings of the model employed, following subsection gives definitions of the model based on Fare et al's study.[10]

[10] Fare, R., Grosskopf, S. and Lovell, C. A. K. (1994a).Production Frontiers, Cambridge: Cambridge University Press.

4.2.1 The Parent Technology

The production process is described by the parent technology which transforms input vectors $x = (x_1,.,x_N) \in R_+^N$ into output vectors $u = (u_1,..,u_M) \in R_+^M$ by the output correspondence *P*, the input correspondence *L*, or by the graph *GR*.

The output correspondence: $P : R_+^N \to P(x) \subseteq R_+^M$ maps input vectors $x \in R_+^N$ into subsets $P(x)$ of output vectors. $P(x)$ is the output set of all output vectors $u \in R_+^M$ that can be produced by $x \in R_+^N$.

The input correspondence: $L(u)$ is all input vectors that can be produced the output $u \in R_+^M$. $L : R_+^M \to L(u) \subseteq R_+^N$ maps output vectors $u \in R_+^M$ that can be produced by $x \in R_+^N$.

The input and output correspondence are inverses in the sense of $u \in P(x) \Leftrightarrow x \in L(u)$ i.e. u belongs to the output set for x iff x belongs to the input set of u.

Defn: An input-output vector $(x,u) \in R_+^{N+M}$ is feasible iff $x \in L(u)$ and $u \in P(x)$

Defn: The collection of all feasible input-output vectors defined by *Gr* i.e.

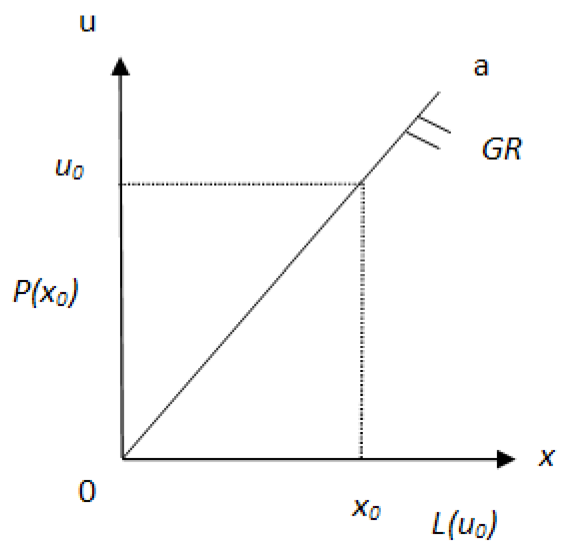
$$Gr = \{(x,u) \in R_+^{N+M} : u \in P(x), x \in R_+^N\}$$

$$= \{(x,u) \in R_+^{N+M} : x \in L(u), u \in R_+^M\}$$

As stated in Fare et al. study the graph is derived from either output or input correspondence and conversely these two correspondences may be derived from graph in accordance with

$$P(x) = \{u : (x,u) \in Gr\} \text{ and } L(u) = \{x : (x,u) \in Gr\}$$

Graph 1 illustrates the relationship among $P(x)$, $L(u)$ and Gr. The graph Gr is bounded by the x-axis and the ray (Oa). Given the input x_0, the corresponding output set $P(x_0)$ consists of close and bounded interval $[0,u_0]$The input set i.e. the inputs that can produce u_0, $L(u_0)$ consists of close but not bounded interval $[x_0,+\infty]$.



Graph 1: Representations of Technology

Proposition 1: $u \in P(x) \Leftrightarrow x \in L(u) \Leftrightarrow (x,u) \in Gr$

Proposition above states that the input sets, the output sets and the graph model the same production technology, although they highlight different aspects of it.

The production technology is assumed to satisfy certain axioms in order to be a valid model of production:

P.1. (a) $0 \in P(x),\ \mathit{for\ all}\ x \in R_+^N$ (zero output vector belongs to the output set (inactivity)

(b) $u \notin P(0), u \geq 0$ (Input is required to produce)

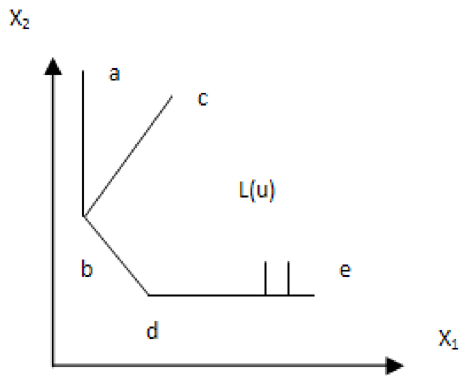
P.2. $\mathit{for\ all}\ x \in R_+^N, \lambda \geq 1, P(x) \subseteq P(\lambda x)$ (Weak Disposability of Inputs)

P.2.S $\mathit{for\ all}\ x, y \in R_+^N, y \geq x, P(x) \subseteq P(y)$ (Strong Disposability of Inputs)

Weak disposability implies that if all inputs are increased in the same proportion i.e.(λx_1,.., λx_N), then no output is lost. This is in the sense that the original production set P(x) is included in P(λx). (Note however that P(x) may equal P(λx), when λ>1).Strong disposability implies that if inputs are increase, the new output set contains the original. Clearly P.2.S implies P.2 but P.2 does not imply P.2.S. The input disposability axioms can be restated in terms of the L(u). P.2 and P.2.S are equivalent to

L.2 $\mathit{for\ all}\ u \in R_+^M, x \in L(u)\ \mathit{and}\ \lambda \geq 1 \Rightarrow \lambda x \subseteq L(u)$

L.2.S $\mathit{for\ all}\ u \in R_+^M, x \in L(u)\ \mathit{and}\ y \geq x \Rightarrow y \subseteq L(u)$



Graph 2: Disposability of Inputs

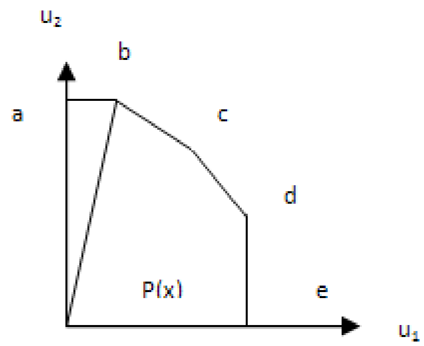
Graph 2 shows the weak disposability and strong disposability of inputs as an illustration. If inputs are only weakly disposable, i.e. P.2 holds but P.2.S does not hold, a typical input set look like L(u) with L(u) consisting of the area bounded by (cbde). Weak disposability allows for "backward bending" isoquant like the segment (c,b). However, an input set in R_+^2 that satisfies strong disposability may look like the area bounded by (abde).

P.3.for all $x \in R_+^N$ and $u \in P(x)$ $0 \leq \theta \leq 1 \Rightarrow \theta u \in P(x)$

(Weak Disposability of Outputs)

P.3.S for all $x \in R_+^N$ and $u \in P(x)$ $0 \leq v \leq 1 \Rightarrow v \in P(x)$

(Strong Disposability of Outputs)



Graph 3: Disposability of Outputs

Weak disposability allows feasible outputs, i.e. $u \in P(x)$, to be proportionally contracted and remain feasible, i.e. $0 \leq \theta \leq 1$ and $\theta u \in P(x)$. Strong disposability allows any feasible output to be freely disposed of, i.e. $u \in P(x)$ and $v \leq u$ imply that v is feasible. The two disposability axioms are illustrated in Graph 3. An output set that satisfies weak but not strong disposability may look like $P(x)$ bounded by (0bcde0) while if strong disposability is satisfied the output set is enlarged to (0abcde0).

If some outputs are desirable and others are not, it is unreasonable to assume strong disposability of outputs since that implies the bads as well as goods can be freely disposed. Therefore, it is assumed that outputs are only weakly disposable. However, the goods are not treated symmetrically with bads. In the output vector $u = (v, w)$, where the sub-vector v denotes the goods and w denotes the bads, it is assumed that u weakly disposable v is freely disposable in the sense that

$$(v, w) \in P(x) \Rightarrow (v^{'}, w) \in P(x) \; for \; v^{'} \leq v$$

To specify a non-parametric linear piecewise technology having disposability properties mentioned above, let $k = 1,2,....,K$ producers using inputs x_k to produce outputs $u_k = (v_k, w_k)$. Denote the $n \times K$ matrix of observed inputs by N, and the $m \times K$ matrix of observed outputs by $M = (V, W)$, where V denotes the sub-matrix of observed desired outputs and W denotes the sub-matrix of observed undesirable outputs. N, V and W are non-negative matrices having strictly positive row sums and column sums.

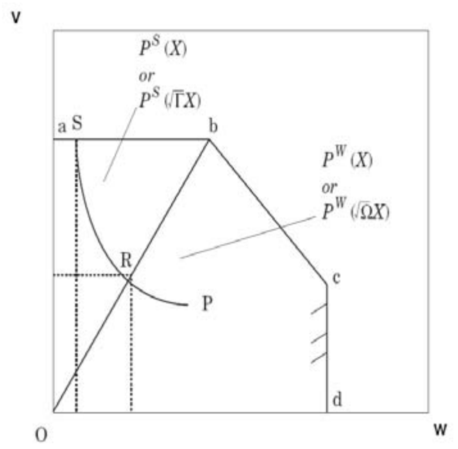
The weak disposal technology associated with the observed data N, M is the output set: $P^w(x) = \{(v,w) : v \leq Vz, w = Wz, Nz \leq x, z \in R_+^K\}$

where z is a $K \times 1$ vector of intensity variables

The strong disposal technology is the output set:

$$P^s(x) = \{(v,w) : v \leq Vz, w \leq Wz, Nz \leq x, z \in R_+^K\}$$

The inequality $w \leq Wz$ allows for strong disposability of undesirable outputs. The output sets for strongly and weakly disposable undesirable outputs can be seen in the Graph 4 below.



Graph 4: Output sets for strongly and weakly disposable undesirable outputs

The next step in the construction of the environmental efficiency index which expand desirable outputs and contract undesirable outputs subject to the constraints imposed by observed inputs and technology. In this case, the environmental efficiency index is the computation of the opportunity cost resulting from the transformation of the production process from one where all outputs are strongly disposable to the one which characterized by weak disposability of undesirable outputs.

For a CRS technology which satisfies the strong disposability of inputs and outputs hyperbolic graph measure of technical efficiency measure is defined for producer k, k=1,…,K as;

$$H_0^A(v^k, w^k, x^k) = \min\{\lambda : (\lambda x^k, \lambda^{-1} v^k, \lambda w^k) \in P^s(x)\}$$

And for each production unit k it can be computed as the solution to the following programming problem

$$
\begin{aligned}
& H_0^A(v^k, w^k, x^k) = \min \ \lambda \\
& s.to \qquad\qquad\qquad\qquad \text{(LP1)} \\
& z^T V \geq \lambda^{-1} v^k \\
& z^T W \geq \lambda w^k \\
& z^T N \leq \lambda x^k \\
& z^T \in R_+^K
\end{aligned}
$$

For computational purposes these nonlinear programming problems in LP1 can be converted into linear programming problem as in LP2 where $\Gamma=\lambda^2$ and $Z=\lambda z$. Then the solution is derived by solving $\sqrt{\Gamma}$

$$
\begin{aligned}
& H_0^A(v^k, w^k, x^k) = \min \ \lambda \\
& s.to \\
& Z^T V \geq v^k \qquad\qquad\qquad \text{(LP2)} \\
& Z^T W \geq \Gamma w^k \\
& Z^T N \leq \Gamma x^k \\
& Z^T \in R_+^K
\end{aligned}
$$

For the technology that assumes weak disposability for the undesirable outputs, and strong disposability for the desirable outputs and inputs, the following linear programming problem can be constructed to obtain the solution $\sqrt{\Omega}$.

$$
\begin{aligned}
& H_0^B(v^k, w^k, x^k) = \min \ \Omega \\
& s.to \\
& Z^T V \geq v^k \qquad\qquad\qquad \text{(LP3)} \\
& Z^T W = \Omega w^k \\
& Z^T N \leq \Omega x^k \\
& Z^T \in R_+^K
\end{aligned}
$$

Finally the environmental efficiency index can be obtained from the ratio of these two efficiency scores as

$$H = \frac{\sqrt{\Gamma}}{\sqrt{\Omega}}$$

As stated in Zaim, Taşkın (2000), H as a measure of environmental efficiency shows the opportunity cost for transforming the production process from one where all outputs are strongly disposable to the one which is characterized by weak disposability of undesirable outputs. Note that, H can take 1 only for the production units which are on the line segments bc and cd since the line segments are common to both technologies. For the cases, where H takes the value less than 1 indicates that there is an opportunity cost due to the transformation. This opportunity cost can be expressed as 1-H which measures the percentage of desirable output given up due to the reduction of undesirable output.

4.3 Data

In order to calculate the environmental efficiency index, we use a panel data set of 27 countries[11] which include OECD and some Asia countries for the 1971-2003 periods. This group of countries is chosen in order to make the sample heterogeneous, and it consists of developed and 5 developing countries chosen from available data. To compute the environmental efficiency indices for each of these countries, aggregate output as measured by real Gross Domestic Products (GDP) are used as the desired output, and Carbon dioxide

[11] The countries are Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Iceland, India, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom and United States

emissions (CO_2) are chosen as a measure of undesirable output. The two inputs considered are aggregate labor input, measured by the total employment, and total capital stock.

GDP data is taken from World Development Indicators (WDI) (2007) which is in constant 2000 U.S. dollars.[12] CO2emissions (kilotons) are obtained from WDI (2007).[13] Employment is the total labor force that participate production (in thousands). Available data on labor is taken from Penn World Table version 6.2 that is computed from GDP per capita, GDP per worker and population variables. Capital is the total physical capital stock (constant in 2000 local prices).[14] Data on capital stocks, are taken from the Nehru-Dhareshwar (ND) database.[15]

4.4 Results

To calculate the environmental efficiency indices for each country two linear programming problems stated in Section 4 are solved for each year by

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[12] GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Dollar figures for GDP are converted from domestic currencies using official exchange rates in 2000.

[13] CO2 emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid and gas fuels, and gas flaring.

[14] Available capital stock is initially constant in 1987 local prices but the base year is converted into 2000 since the GDP data is in constant 2000 U.S. dollars.

[15] For most cases the available data until 1990 is extended to 2003 using perpetual inventory method. For a few of the countries for which the data was not available in this set, an assumption regarding the initial capital output ratio is made and the rest of the series is constructed using the perpetual inventory method.

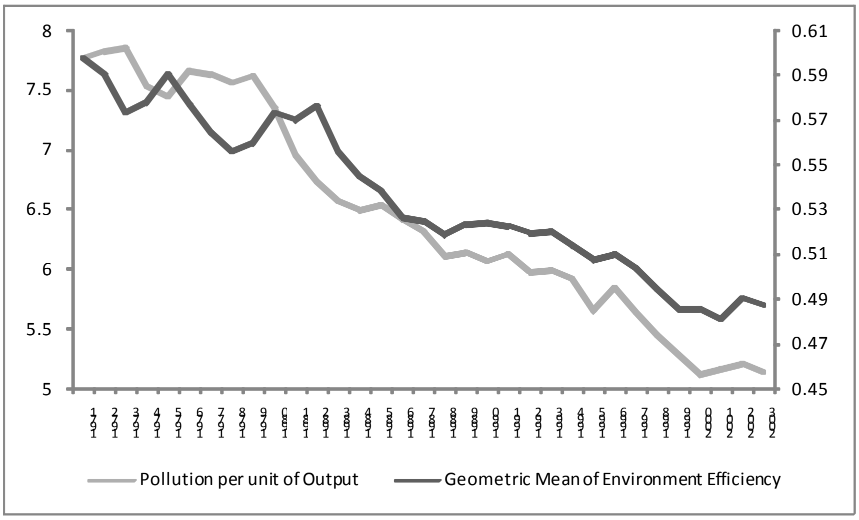
using General Algebraic Modeling System (GAMS) computer program. This procedure is repeated for each year between 1971 and 2003 and 1728 linear programming problems are solved. The ratio of two efficiency numbers computed from two linear programming under the technology that satisfies strongly and weakly disposability of undesirable good gives the index of environmental efficiency for each country. The components of the efficiency index and the resulting environmental efficiency index itself are presented in Table 7.1, Table 7.2 and Table 7.3 respectively.

Table 7.1 and Table 7.2 show the efficiency measures under strong and weak disposability assumptions for pollutants, respectively. Values in these tables show how much inputs and CO_2 emissions can be reduced while simultaneously increasing its outputs and still are in the feasible production sets. To illustrate, in Table 7.1, 0.556 is the value for Australia in the year 1971 under strong disposability assumption of pollutants. This means that the output of Australia can be increased by GDP/0.556 while simultaneously contracting the inputs by Input ×0.556 and CO_2 emission by CO_2 emission × 0.556 and remain still in the feasible production set. On the other hand, in Table 7.2, 0.785 is the value for Australia in 1971 under weak disposability of pollutants and shows that the output of Australia can be increased by GDP/0.785 amount while simultaneously contracting the inputs by Input×0.785 and CO_2 emission by CO_2 emission×0.785 and remain still in the feasible production set.

The values in Table 7.3 are the ratios of corresponding values in Table 7.1 and Table 7.2 and they measure the opportunity cost due to the transformation of the desirable output in order to reduce the undesirable output. In this table, it is seen that the measure of environmental efficiency takes the value of one for the USA and the UK and less than one for the other countries during the entire sample period. In other words, it can be concluded that the USA and the UK are fully efficient such that there is no opportunity cost for transforming the production process from the one where all outputs are strongly disposable to the one which is characterized by weak disposability of undesirable outputs. For all countries the efficiency measures computed with strong disposability assumption of bad output is lower than the ones computed with weak disposability assumption, in accordance with the theoretical model presented in the previous section. For example, Switzerland is a country that is fully efficient under weak disposability of undesirable good but it is inefficient under strong disposability assumption.

The analysis shows that among all of the 27 countries whereas the UK and the USA have the highest environmental efficiency scores, Mexico, Korea, Thailand and Turkey have the lowest environmental efficiency scores. During the sample periods, Australia, India, Ireland, Korea and Thailand are the only countries that can improve their efficiency scores and most of the other countries such as Iceland, France, Denmark, Mexico and Netherlands reduce their environmental efficiency scores.

The overall picture can be captured by the geometric mean of the environmental efficiency indexes of all countries presented in the following Graph 5 below: It is seen that the environmental efficiency index is deteriorating through time.[16] We compare the geometric mean value of the environmental efficiency index to the total pollution per unit of output as another indicator of environmental quality. In this period both the environmental efficiency index and the pollution per output decline. The decline in the efficiency scores point to the deterioration of the environmental performance whereas pollution per output measures indicate an improvement.

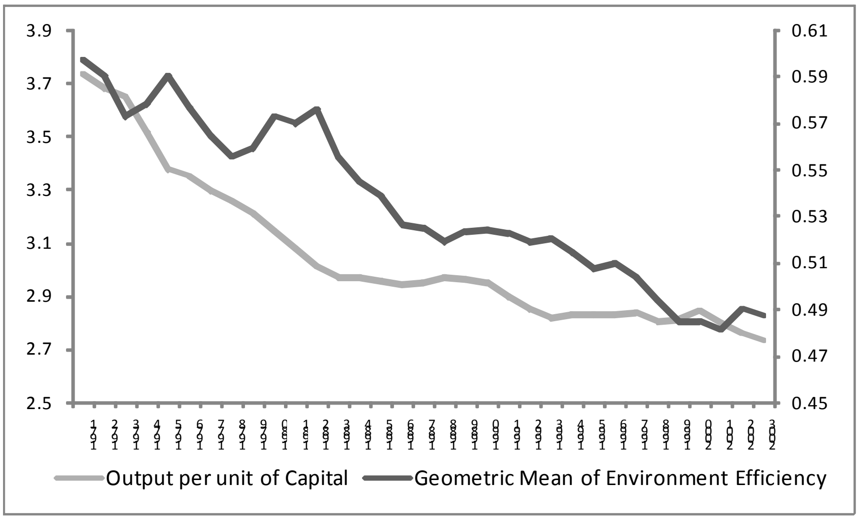


Graph 5: Comparison of mean efficiency and total pollution per output

Even though there is no obvious reason for this contradictory result, one may look into the details of the environmental efficiency techniques. Firms' decisions on input use and output mix are taken into consideration in efficiency measures whereas pollution per output isolates only two factors. In this sample of countries we see that production become capital intensive as pollution

[16] Table 7.3.1 shows the period averages of the environmental efficiency index for all countries.

intensity measured by pollution per output declined. As illustrated in Graph 6, average output per capital declines and capital per output increases. This might be a reflection of, countries effort to decrease pollution, move to capital intensive technologies. From a perspective of input minimization and output maximization, this change led countries to produce at an environmentally less efficient level.[17] Further examination of the properties of the environmental efficiency measurement techniques and the details of the production processes is necessary in order to expose the relationship between alternative environmental performance measures, which is beyond the scope of this study.



Graph 6: Comparison of mean efficiency and total output per unit of capital

For further analysis of the environmental efficiency values, we group our sample into developed and developing countries in accordance with World Bank

[17] Moreover, the capital-labor ratio increases while pollution per unit of capital decreases that supports that claim that the efficiency is declining through time as capital usage is increasing.

classification.[18] Graph 7 below shows the comparison of the geometric mean of the environmental efficiency for these two groups. As expected developed countries have higher environmental efficiency indices than the developing countries for the entire period. This supports the Environmental Kuznets Curve Hypothesis that explains the relationship between environmental efficiency and income by a U-shaped curve.[19] When we examine the change in the average efficiency scores overtime we see that there is an efficiency gain in developing countries but developed countries' environmental efficiency deteriorates through time.[20] With this result it may be possible to infer that as a group of our middle income developing countries are located in the upward sloping part of the Kuznet's curve. Even though this second results seems to contradict the quadratic form of the EKC hypothesis; it may be in line with the higher order polynomial EKC curves mentioned in the literature.[21]

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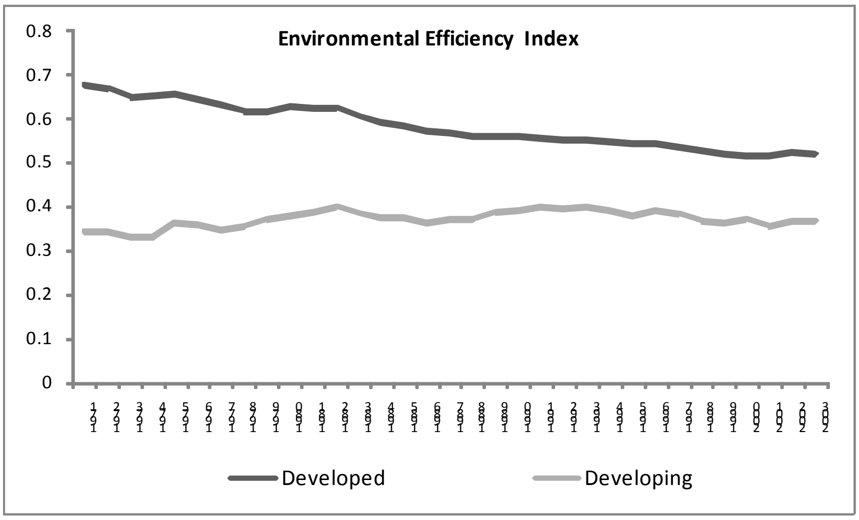
[18]The developed countries are Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and United States. The developing countries are India Korea, Mexico, Thailand and Turkey.

[19] Environmental Kuznets curve hypothesis is an inverted-U shape relationship between pollution emission and income, which indicates an initial deterioration and then improvement in the environmental efficiency as a country move to higher income levels. (Richmond, et.al. (2007) "Environmental Kuznets curve.")

[20] There is little evidence that EKC relationship holds for the emissions of greenhouses gases. Especially, for CO_2 which is the pollutant in this study, the support of EKC is either weak or finds a considerably higher income level such as 33000$ per capita as the possible turning point. (Zaim.,Taşkın 1999)

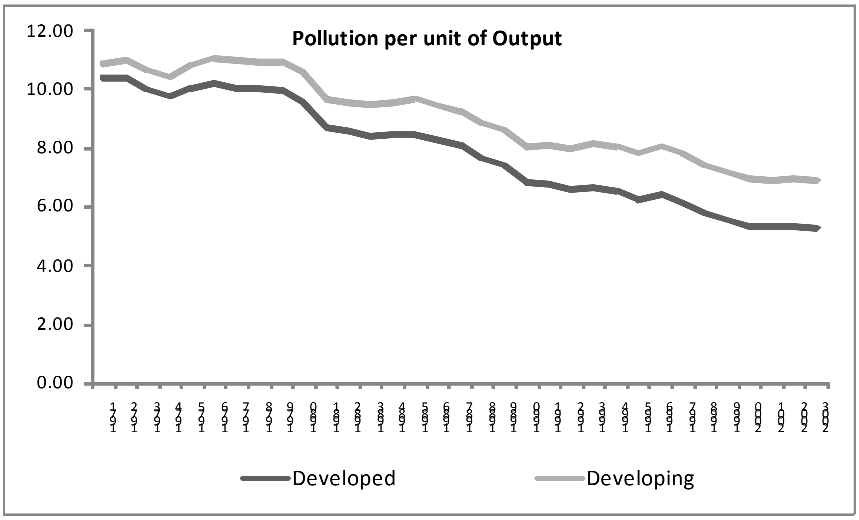
[21] Robust to the finding of Zaim, O. and Taskin, F. (1999) that states a new kind of Kuznets curve relationship which implies an improving environmental performance at initial phases of growth which is followed by a phase of deterioration and then a further improvement once a new critical level of per capita GDP is reached.



Graph 7: Comparison of mean efficiency for developed and developing countries

To examine the differences in the developed and developing countries further, Graph 8 reports the pollution per unit of output ratio for these two groups. As expected, pollution per unit of output is higher for the developing countries than the developed countries which support the environmental efficiency results and Environmental Kuznets Curve Hypothesis. Furthermore, there is a rapid decline in the total pollution per unit output with improved environmental performance for developing countries according to this measure too. Hence, there is an improved performance of the environmental quality for this sample of developing countries overtime. However, for developed countries group even though pollution per output declines we do not observe an improvement in their average environmental efficiency. [22]

[22] In comparison of their production processes, we observe that GDP per capital is higher in developed countries than in developing group. Moreover, the capital-labor ratio in developed



Graph 8: Comparison of total pollution per unit of output for developed and developing countries

With the results of the environmental efficiency values it is possible to compute the opportunity cost of transforming the production process from the one where all outputs (good or bad) are freely disposable to the one where pollution emissions are costly to dispose. We compute the output loss as (1-H)× GDP in constant 2000 prices. Table 7.4 shows for each country, the average value of output loss in billion dollars for the selected periods. The total average value of output loss for the countries as a whole is found 314 billion US dollars. In terms of the individual countries, since the USA and the UK have found to be

countries is higher than developing countries. These differences might be the indicates of the changes in the production processes in achieving the lower output per pollution values.

fully efficient, there is no output loss of these countries. Moreover, France and Japan have the highest opportunity costs among the countries.[23]

Using the results of the environmental efficiency measures, we want to investigate the role of environmental performance on bilateral trade volumes. The next section presents the empirical analysis of a gravity model of trade with environmental efficiency index.

[23] These results are robust with the conclusions of Zaim, Taşkın (2000) and OECD report (1991) stated in their study.

CHAPTER V

ESTIMATION OF GRAVITY MODEL WITH ENVIROMENTAL EFFICIENCY INDEX

5.1 Data

By using a Gravity Model of trade, the effect of environmental efficiency on trade is examined. The data for the bilateral trade flows are the total bilateral exports (in billions of US dollars) obtained from Direction of Trade Statistics in IMF International Statistics. Export Price Indices from World Development Indicator are used to convert bilateral trade flows from nominal values into the real variables. The income data were obtained from WDI (2007) and it is GDP (constant 2000 US Millions Dollars) at purchaser's prices is the one that is used in the computation of environmental efficiency index.

5.2. Model

Exports of 27 countries in the sample, for period 1971 and 2003, are examined by the estimation of the following gravity model of trade:

$$lnX_{ij} = ln\beta_o + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnDist_{ij} + \beta_4 lnEFI_i + \beta_5 lnEFI_j + u_{ij}$$

with

X_{ij} = Total exports of country i to country j in millions of US dollars

Y_i = Gross Domestic Product of country i in millions of US dollars

Y_j = Gross Domestic Product of country j in millions of US dollars

$Dist_{ij}$ = Distance between country i and j in nautical miles

EFI_i = Environmental Efficiency Index in exporting country i

EFI_j = Environmental Efficiency Index in importing country j

u_{ij} = Log-normally distributed disturbance term

In gravity equation bilateral trade is considered to be dependent on the exporting country's income which is assumed to be positively related to total exports, the importing country's income which is also assumed to be positively related to total exports and the distance between these two countries which is a good proxy for transportation costs is assumed to be negatively related to total exports.

These three variables explain what has been called the Gravity Model of bilateral trade between country i and j. It is expected that β_1 and β_2 are positive and that β_3 is negative.

In order to take account of environmental efficiency effect on bilateral trade the basic gravity model is extended with the addition of the environmental efficiency variables i.e. EFI_i and EFI_j. These variables, EFI_i and EFI_j are used to test the hypothesis whether stringent domestic environmental policies, which are measured as environmental efficiency, have an effect on comparative advantage and hence trade amounts. If high environmental efficiency for the exporting country is the result of stringent environment regulations and hence higher cost of production, the country will lose comparative advantage in production of this good which in turn leads to a decline in its exports. Then we expect to see a negative coefficient for β_4. On the other hand, if the high environmental efficiency is observed in the partner country, by the same reasoning it might be an indication of the loss of comparative advantage and increased demand for imports, which will lead to a positive coefficient for β_5.[24]

5.3. Empirical Results

In testing for presence of environmental efficiency effect on bilateral trade, equation (1) is estimated. The results are reported in Table 7.5 where the dependent variable which is the total exports of country i to j is estimated by pooled OLS method for the sample period. Column (1) corresponds to the simple gravity model in which bilateral exports of two countries is explained by the income of these two countries and the distance between them. In this simple model, all explanatory variables show statistically significant and theoretically expected signs with R^2=0.733.

According to White Heteroscedasticity test based on Model 1 results, there is strong evidence of heteroscedasticity in the data which will make the

[24] The above analysis takes into account the demand side of the bilateral trade volumes and assumes that countries are different in terms of their environmental policies and these differences indicated by different EFI_i and EFI_j values that will have a significant impact on their exports.

estimated coefficients inconsistent. Moreover, the Wooldridge Test for autocorrelation in panel data set is applied to this model and the hypothesis that there is no autocorrelation is rejected and it is concluded that the error terms are correlated with each other. Therefore, in Column (2) of the Table 7.5, the coefficients' standard errors are corrected using White Heteroscedastic robust standard errors and the autocorrelation is corrected by clustering the countries. It can be seen that results remain the same with the previous models with robust estimators in this corrected model.

Gravity Model with environmental efficiency measures are reported in column (3) of the Table 7.5. Taking the gravity equation as a reference model, the question whether the environmental efficiencies affect bilateral trade or not is explored in this model. It is found that there is a statistically significant relationship between both countries' environmental efficiency indices and the bilateral exports between these two countries in the model reported in column (3). Although they are significant, the sign of the efficiency index of the exporting country does not have an expected sign.[25] However, the sign of the environmental efficiency index of importing country is both significant and has a theoretically expected sign.

[25] On the other hand, in the supply side of the gravity equation, countries may increase their imports from trade partners that protect the environment properly because they want high quality and considers the environmental concerns.

According to the results of the White Heteroscedasticity test and Wooldridge Test for autocorrelation[26], the necessary corrections are made and the results are reported in the last column of the table. In this model, the environmental efficiency of country i is positive and significant at 5% level and the environmental efficiency of country j is positive and significant at 1% level. The variables of the gravity model continue to be significant with expected signs.

Furthermore, in table 7.6 the same models in Table 7.5 are estimated with country fixed effects to capture this relationship according to the country specific effects. Therefore, Model 1 and Model 2 in Table 7.6 represent the Simple Gravity model with country fixed effects. In Model 2 with robust and clustered standard errors, all of the estimates show statistically significant and theoretically expected signs with an increased R^2=0.828. The difference between pooled OLS and fixed effect model of the simple Gravity equation is the increased magnitude of exporting country's income coefficient and R^2.

Then Model 3 in the third column of Table7.6 is the gravity model with environmental efficiency variables estimated with fixed effects. Model 4 reported in column (4) is the same model corrected from heteroscedasticity and autocorrelation. Once the country special factors are taken into account with fixed effect model, it is found that in the export equation the country's own environmental efficiency is not statistically significant. On the other hand, in

[26] Reported in Table 7.7.

export equation, the environmental efficiency of the partner (importing) country's environmental efficiency is positive and significant at 1% level. The results of this final model lead to the following conclusions: (i) the impact of country's own environmental efficiency on the bilateral exports of this country is not statistically significant. (ii) the impact of the partner country's environmental efficiency on exports of a country is positive and highly significant. (iii) the higher the environmental efficiency of a country, the larger will be its imports from its partner countries. (iv) the income and distance variables of the gravity model have maintained their strong explanatory power for bilateral trade.[27]

Moreover, these results indicate that the improvement in the environmental efficiency of a country may lead to an increase in its imports from other countries, rather than a significant change in its own exports. It is probably due to the fact that the volume of imports is mostly determined by their own decisions and their own conditions have more effect on their decisions. In other words, countries have more power in the determination of the amount of their imports than their exports so their own environmental efficiency mostly affects their own decisions instead of the other countries' decisions.

The same models are estimated using random effects models and the results are reported in Table 7.9. The last column of this table represents the

[27] In order to make the sample homogenous, we restrict our data for developed countries by dropping the developing countries. For this data set, gravity model with environmental efficiency index, country fixed effects and robust clustered standard errors are estimated. In this homogenous set of countries, it is found that exporting country's own environmental efficiency index is significant at $\alpha=0.15$ significance level and it has a negative effect on the bilateral exports of this country. Moreover, the partner country's environmental efficiency index continues to be significant a 1% and maintains its positive magnitude.

equation (1) with corrected standard errors. The Haussmann test under the null hypothesis that is random effect is consistent is applied to the model and the hypothesis is rejected under 0.01 significance level. Therefore, we can conclude that fixed effect model with corrected standard errors reported in the last column of the Table 7.6 is selected as the estimate of the equation (1)[28].

Following Table 7.7 shows the diagnostic test results of the model represented in equation (1). It can be seen that there are heteroscedasticity and autocorrelation in the model which are corrected by using robust clustered standard errors. To test for the multicollinearity among the independent variables, VIF values are calculated and it can be concluded that there is no multicollinearity between independent variables of this model. Finally, normality assumption is checked by looking the Kernel density estimate graph which represents that the error terms are distributed normally.

5.4. The Extensions of Gravity Equation with New Variables and Dummies

In the literature gravity model is complemented and extended to include factors such as population, land area and other dummy variables that accounts for adjacency, language and belonging to a common trade area. In this section, the gravity model is extended to include these factors to evaluate the importance

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[28] Egger (2004) demonstrates by the Hausman χ^2-test that the proper econometric specification of a gravity model in most applications would be the fixed country effects.

of environmental efficiency with the addition of these variables. Hence, the fixed effect models are reestimated with these variables.

In order to extend the model and give a further analysis of the relationship between environment and trade flows, population values of the bilateral countries are added into equation(1). As the income variable in the gravity model, population also represents the country's potential supply and demand for exports and imports respectively. In other words, population is a good approximation for the effects of economies of scale. A country with a large population can much easily specialize in a wide range of commodities and, consequently, may be less dependent on foreign trade which will lead to a negative coefficient. Alternatively, if the demand factors are dominant the variable might result in a positive effect on exports.

Land variables are assumed to have negative influence on trade. The larger a countries' total area, the smaller the fraction of its economic activity that is expected to cross borders and the higher probability of relatively closed economy. Finally, three dummy variables which shed light on the circumstance of being a neighbor, the circumstance of sociologic differences like language or the membership of a union are included in the model. The coefficients of these dummy variables are both expected to be positive as their existence all increase the level of bilateral trade.

With these added seven new variables in equation (2) we hope to account for all the factors affecting bilateral trade and evaluate the impact of the environmental efficiency.

$$lnX_{ij} = ln\beta_o + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnDist_{ij} + \beta_4 lnEFI_i + \beta_5 lnEFI_j + \beta_6 lnPop_i + \beta_7 lnPop_j + \beta_8 lnLand_i + \beta_9 lnLand_j + \beta_{10} A_{ij} + \beta_{11} Lang_{ij} + \beta_{12} EU_{ij} + u_{ij}$$

with:

Pop_i = Population of country i.

Pop_j = Population of country j.

$Land_i$ =Land area of country i.

$Land_j$ =Land area of country j.

A_{ij} =dummy with value 1 if both exporter i and importer j are adjacent countries[29] and zero otherwise.

$Lang_{ij}$=dummy with value 1 if both exporter i and importer j speak the same language and zero otherwise.

EU_{ij}=dummy with value 1 if both exporter i and importer j are a member of the European Community and zero otherwise.

In Table 7.8 the new equation (2) is estimated for five different models with country fixed effects and corrected standard errors. In order to make comparison, Model 1 is the repetition of the estimate of the equation(1) found in the last column of Table 7.6. Model 2 in the second column of Table 7.8, the population variables of the countries' are included into the model. Here all results for the analysis of the environmental efficiency and gravity model is same as the previous model and the added new population variable coefficients' are found to be statistically insignificant. With further additions to the model,

[29] Both land and sea adjacencies are taken into consideration.

land variables have the significant coefficients with expected negative signs. Adjacency variable is found to have a positive significant effect on bilateral exports. Moreover, speaking the same language has also a positive significant effect on the bilateral exports. The European Union dummy variable on the other hand is not significant with positive sign. In all the extended gravity models, the signs of the trade model such as GDP and distance variables are significant and expected signs, and conclusions regards environmental efficiency variables are maintained that the environmental efficiency of country j is significant at 1% level and has the expected sign.

Among all models, model 5 is chosen to be a better estimate of the equation (2). The results can be summarized as follows (i) the impact of high environmental efficiency of the exporting country on the bilateral exports of this country is statistically insignificant. (ii) the environmental efficiency of importing country has a theoretically expected statistically significant coefficient. (ii) the land variables of the countries are negatively related to the bilateral exports as expected and they are also found to be significant. (iii) if these two countries are adjacent, the bilateral exports will increase. (iii) if these two countries speak the same language, bilateral exports will also increase.

5.5. Robustness Check

5.5.1 Endogenity Problem between Exports and Income Levels of the Countries

Since international trade flows has a significant part of GDP, which is one of the regressor of the equation, there may be a causality problem in the gravity model. Then, the OLS estimation of the coefficients will be inconsistent. In order to solve this problem, in this section instrumental variable technique is used and five years lagged GDP variables which are highly correlated with the independent variable GDP and yet are independent of the error term are selected as a possible instrument.[30]

The endogenity problem between exports and GDP of the countries is addressed in Table 7.10. Here, previous models starting from simple gravity, simple gravity with environmental efficiency and extended gravity model are estimated with five year lagged values of the countries income levels. From this table it can be concluded that our previous results are still valid for all models.

The last column of Table 7.10 as decided to be a better model can be summarized as follows: the environmental efficiency index of importing country has a significant positive effect on this country's imports. In other words, 1%

[30] Bandyopadhyay (1999)

increases in the efficiency of the importing country leads to 0.736% increase in total exports to this country.

5.5.2 Restrictions on the coefficients of Environmental Efficiency Index

In Table 7.11 the model with relative efficiency index is analyzed in order to compare the bilateral efficiency scores with each other. In this case, we restrict the coefficients of the environmental efficiency indices to be equal to each other i.e. $\beta_4=\beta_5$. The simple gravity model with environmental efficiency and the last model in Table 7.8 are estimated with $lre=\ln(e_j/e_i)$ denoting the relative efficiency measure of these two countries instead of analyzing the environmental efficiency indices separately. Here with robust standard errors it is found that there is a statistically significant effect of relative efficiency of two countries on bilateral exports. Moreover, it has a positive sign that means if the relative environmental efficiency index increases, in other words if the importing country's environmental efficiency index is bigger than the exporting country's environmental efficiency index, then the total bilateral export between these two countries is going to increase. Mathematically, 1% increase in relative efficiency makes exports increase by 0.695%.

It is important to check the null hypothesis of $H_0:\beta_4=\beta_5$ since to use relative efficiency index we restrict our model under this hypothesis. Applying the Chow Test to the last model in Table 7.8, we have found the p-value of the test statistic is 0.0029 so we can reject the null hypothesis under 0.01 α-level. Then, the hypothesis of working with relative efficiency is rejected. Therefore, it is important to conclude that the importing country's environmental efficiency index has more power on the volume of imports to this country than the exporting county's environmental efficiency index.

CHAPTER VI

CONCLUSION

This study examined the relationship between environment and trade. Employing Gravity Model, in which the volume of bilateral trade between two countries is proportional to the product of their masses (GDPs) and inversely related to the distance between them, the impact of environmental efficiency on trade flows is analyzed. The aim is to examine the role of environmental conditions on bilateral trade volumes across countries.

Following Farrell (1957) and Fare et al. (1989) we measured environmental condition with environmental efficiency index. The index is derived from a hyperbolic measure of technical efficiency in a non-parametric piecewise linear technology. This analysis follows the logic that the production plan maximizes the desirable outputs while simultaneously minimizing the resource use and pollution emissions. It is possible to compare hyperbolic measure of technical efficiency in a technology that satisfies weak and strong disposability of undesirable outputs. The difference between the weakly and strongly disposable technologies enables us to quantify desirable output loss due to the lack of strong disposability of undesirable outputs. Environmental efficiency shows the opportunity cost for transforming the production process from one where all outputs are strongly disposable to the one which is characterized by weak disposability of undesirable outputs.

First, environmental efficiency index are calculated for a 27 countries comprised from OECD and some Asian countries for the period 1971-2003 using GAMS software. The results indicate that the geometric mean of the environmental efficiency index for whole sample is deteriorating as time goes by. The UK and the USA have the highest environmental efficiency scores, whereas Mexico, Korea, Thailand and Turkey have the lowest mean environmental efficiency scores.

The relationship between bilateral exports and environmental efficiency index is investigated. First, Pooled Ordinary Least Squares (OLS) estimator is utilized to expose the relationship between trade and environment. Then, we add country fixed effects to the model under robust standard errors. Next, we extent our model by adding new variables such as population, land and to account for dummies such as adjacency, language and belonging to a common trade area. Furthermore, we do a set of robustness check with the consideration of the endogenity problem and the case in which the coefficients of the environmental efficiency is equal to each other.

Under these studies the results indicate that there is a strong, positive and significant relationship between the exports and the environmental efficiency index of importing country. However, the impact of the environmental efficiency of the exporting country is not statistically significant probably due to the fact that countries are more capable of controlling their own purchase decisions than the other countries decisions on the level of trade. In other words, countries are more powerful to determine the amount of their imports than their exports so their own environmental efficiency affects their purchase decisions of their imports.

The sample includes mainly OECD countries with high income economies that have similar environmental concerns. When we restrict our sample countries into developing countries, it is found at $\alpha=0.15$ significant level, there is a negative impact of countries' own environmental efficiency index on their exports. Furthermore, this kind of homogenous group analysis is going to be studied in the future.

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APPENDICES

APPENDIX A

The Theoretical Review of Gravity Model

Deardorff[31] derives gravity equation under Heckscher-Ohlin Model. Since our theoretical framework is adopted from his article, here his study is going to be summarized deeply in order to achieve the theoretical base of the gravity equation. In his paper he first emphasized on Frictionless trade case -- that is zero barriers to trade including tariff and transportation costs. Then, he analyzed the other case of trade with trade impediments for H-O model.

In frictionless trade case, he considers a H-O model with any numbers of goods and factors. For this model, each country is a net exporter of some good to the world market and a net importer of others. There are vectors of production, consumption and net trade in each country are consistent with maximization by perfectly competitive producers and consumers in all countries for all goods and such that world markets clear. Then, he considers that producers put their outputs into a world pool and consumers choose randomly

[31] "Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?" Deardorff, Alan V.The Regionalization of the World Economy.Chicago: University of Chicago Press. (7-22)1998.

their desired levels of consumptions from these pools. Under identical and homothetic preferences he sets x_i as county i's vector of production and c_i as its vector of consumption in a frictionless trade equilibrium with world price vector p. Its income is therefore $Y_i = px_i' = pc_i'$, so that expenditure equals income. Consider the value of exports from country i to country j is T_{ij}. With identical, homothetic preferences all countries will spend the same fraction β_k of their incomes on good k, so that j's consumption of good k is $c_{jk} = \beta_k Y_j / p_k$. Drawing randomly from the world pool of good k, to which country i has contributed the fraction $\gamma_{ik} = x_{ik}/h_k$, country j's purchase of good k from country i will be $c_{ijk} = \gamma_{ik}\beta_k Y_j / p_k$. Let $x_k^w =_i x_{ik}$ be world output of good k, with identical fractions of income being spent on good k by all countries, that fraction must also equal the share of good k in world spent income, $Y_w : \beta_k = p_k x_k^w / Y_w$

The value of j's total imports from i Tij is:

$$
\begin{aligned}
T_{ij} &= \sum_k p_k c_{ijk} = \sum_k \gamma_{ik}\beta_k Y_j \\
&= \sum_k \frac{x_{ik}}{x_k^w}\frac{p_k x_k^w}{Y^w} Y_j = \sum_k p_k x_{ik} \frac{Y_j}{Y^w} \\
&= \frac{Y_i Y_j}{Y^w}
\end{aligned}
$$

Therefore, with identical, homothetic preferences and frictionless trade, a simpler gravity equation is derived with constant proportionality $A = 1/Y_w$. Here, distance plays no role since there are no transport costs and the value of j's total imports from i is determined by the income of these countries.

In Impeded Trade case, there are strictly positive identical trade barriers for every good. Every county produces and exports different good (extreme specialization) and there are unequal factor prices in each pair of countries. In this case he identifies each good with the country that produces it and enters them into a utility function as imperfect substitutes and with transport factor between countries i and j being t_{ij} a fraction $(t_{ij} - 1)$ of the good shipped from country i is used in transport to country j. With perfect competition, sellers receive single price pi and buyers price will be $t_{ij} \times p_i$. Under identical and Cobb-Douglas preferences, consumers in each country spend a fixed share β_i of their incomes on the product of country i.

Country i's income Yi is $Y_i = p_i * x_i = \sum_j \beta_i Y_j = \beta_i Y^w \quad where \quad \beta_i = Y_i / Y^w$

Then trade can be valued either exclusive of transport cost (f.o.b) or inclusive of transport cost (c.i.f) [32]

Under C.i.f basis he gets (inclusive transport cost) $T_{ij}^{cif} = \beta_i Y_j = \dfrac{Y_i Y_j}{Y^w}$

Under F.o.b basis he gets (exclusive transport cost) $T_{ij}^{fob} = \dfrac{Y_i Y_j}{t_{ij} Y^w}$

Therefore, with Cobb-Douglas preferences, he gets the simple frictionless gravity equation for c.i.f. trade, with no role for transport cost or distance. On an f.o.b. basis, however, these flows must be reduced by the amount of the transport cost. To the extent that transport cost is related to distance, this immediately gives a result very similar to the standard gravity equation.

[32] Freight-on-Board (FOB) cost structures involve the production cost plus any transport costs to the customers. This implies that customers located nearby will have a lower overall cost than customers that are further away. Under the Cost-Insurance-Freight (CIF) cost structure, every consumer is charged the same price, which commonly reflects the average transport cost.

He changes preferences assumption and analyzes the case in which he assumes preferences as CES. In these model consumers in country j maximize the following CES utility function defined on the products of all countries

$$U^j = \left(\sum_i \beta_i c_{ij}^{\left(\frac{\sigma-1}{\sigma}\right)} \right)^{\frac{\sigma}{\sigma-1}} \quad where \quad \sigma > 0$$

subject to their income

$$Y_j = p_j x_j \quad from \quad producing \quad x_j$$

Then, they will consume

$$c_{ij} = \frac{1}{t_{ij} p_i} Y_j \beta_i \left(\frac{t_{ij} p_i}{p_j^I} \right)^{1-\sigma}$$

$$where \quad p_j^I = \left(\sum_i \beta_i t_{ij}^{1-\sigma} p_i^{1-\sigma} \right)^{1/(1-\sigma)} \quad is\ a\ CES\ price\ index\ of\ landed\ prices\ in\ counrty\ j$$

Therefore the f.o.b value of exports from i to j is

$$T_{ij}^{fob} = \frac{1}{t_{ij}} Y_j \beta_i \left(\frac{t_{ij} p_i}{p_j^I} \right)^{1-\sigma}$$

The c.i.f value of trade is

$$T_{ij}^{cif} = Y_j \beta_i \left(\frac{t_{ij} p_i}{p_j^I} \right)^{1-\sigma}$$ is decreasing in t_{ij} if $\sigma>1$.

Here the parameter β_i is no longer country i's share of world income, as it was in the Cobb-Douglas case, so this does not reduce as easily to the standard gravity equation. However, if we let θ_i country i's share of world income, we can relate it to β_i as follows:

$$\theta_i = \frac{Y_i}{Y^w} = \frac{p_i x_i}{Y^w}$$

$$= \frac{1}{Y^w}\sum_j \beta_i p_j x_j \left(\frac{t_{ij} p_i}{p_j^I}\right)^{1-\sigma}$$

$$= \beta_i \sum_j \theta_j \left(\frac{t_{ij} p_i}{p_j^I}\right)^{1-\sigma} \quad \textit{from which} \quad \beta_i = \frac{Y_i}{Y^w}\frac{1}{\sum_j \theta_j \left(\frac{t_{ij} p_i}{p_j^I}\right)^{1-\sigma}}$$

Using this he gets:

$$T_{ij}^{fob} = \frac{Y_i Y_j}{Y^w}\frac{1}{t_{ij}}\left[\frac{\left(\frac{t_{ij}}{p_j^I}\right)^{1-\sigma}}{\sum_h \theta_h \left(\frac{t_{ih}}{p_h^I}\right)^{1-\sigma}}\right]$$

To simplify this let p_i is normalized to unity. Then p_j^I becomes a CES index of country j's transport factors as an importer, what will be called its average distance from suppliers δ_S :

$$\delta_j^S = \left(\sum_i \beta_i t_{ij}^{1-\sigma}\right)^{\left(\frac{1}{1-\sigma}\right)}$$

With defining relative distance from suppliers as $\rho_{ij} = \frac{t_{ij}}{\delta_j^S}$, the trade flow becomes;

$$T_{ij}^{fob} = \frac{Y_i Y_j}{Y^w}\frac{1}{t_{ij}}\left[\frac{\rho_{ij}^{1-\sigma}}{\sum_h \theta_h \rho_{ih}^{1-\sigma}}\right]$$

The main results from this equation are, if importing country j's relative distance from exporting country i is same as an average of all demanders' relative distance from i, then we get the same result as in the Cobb-Douglas Case. If j's relative distance from i is greater than this average, then bilateral trade flows become smaller. If j's relative distance from i is smaller than this average, then bilateral trade flows become larger. The greater is the elasticity of substitution among goods, the more will trade between countries.

APPENDIX B

Technical Efficiency Measure

To understand the basic of technical efficiency, Farrell work[33] is going to summarized in this section. In his paper, Farrell assume for the sake of simplicity a firm employing two factors of inputs to produce a single output. Under constant return to scale, he suppose the efficient production function is known (he relax these two cases). In the Diagram 1, the point P represents the inputs of two factors that the firm has to produce the output. Let SS` be the perfectly efficient isoquant, such that point Q represents an efficient usage of two inputs. Under constant returns to scale assumption, since points P and Q uses the two factors in the same ratio, point Q produces the same output as P using only a fraction OQ/OP as much of each factor. In other words, it can produce OP/OQ times as much output from the same input. Thus, OP/OQ can be defined as "technical efficiency" of a firm.

[33] Farrell, M.J. (1957) "The Measurement of Productive Efficiency." Journal of the Royal Statistical Society 120(3):253-290.

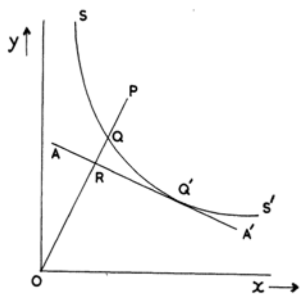


DIAGRAM 1.

Here, the assumption that the efficient production function is known is not realistic. The problem to estimate it from observations of inputs and outputs of firms is significant before discussing the significance of the efficiency measures. To estimate it from observations, each firm is represented by a point on an isoquant diagram, so that a number of firms will yield a scatter of points like that on Diagram2. Under the assumptions that isoquant is convex to origin has nowhere a positive slope, the SS` is the most conservative estimate of the perfect efficient isoquant line. It is clear that two points are attainable then, we can derive SS` from weighted average of these two points. It will be seen that this method of measuring the technical efficiency of a firm consists in comparing it with a hypothetical firm which uses the factors in the same proportions and this hypothetical firm is constructed as a weighted average of two observed firms, in the sense that each of its inputs and outputs is the same weighted average of those of the observed firms.

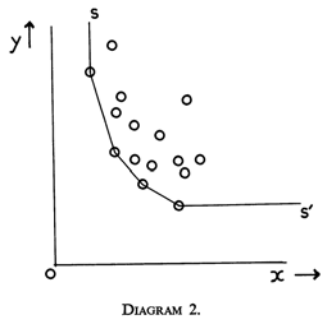


DIAGRAM 2.

To derive SS` mathematically, there are two assumptions to be satisfied that SS` s slope is not positive and no observed points lies between SS` and the origin. These two conditions can be expressed as an algebraic definition as follows:

Let (x_{i1}, x_{i2}) be any point in the SS' and λ_{ijk} and μ_{ijk} be the solution of the equations

$$\lambda_{ij1} + \mu_{ij1} = x_{k1} \qquad (1)$$

$$\lambda_{ij2} + \mu_{ij2} = x_{k2}$$

where P_i, P_j and P_k are points in SS'. Then the line segment joining P_i and P_j is part of SS'`if and only if

$$\lambda ijk + \mu ijk \geq 1 \text{ for all } P_k \in SS'$$

Thus the equation (1) can be used to determine the technical efficiency of any point P_k.

APPENDIX C

Table 7.1 Efficiency index under strong disposability of undesirable Outputs √Γ

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Australia	0.556	0.545	0.521	0.526	0.533	0.531	0.526	0.526	0.525	0.535	0.540
Austria	0.413	0.405	0.393	0.406	0.409	0.398	0.391	0.373	0.374	0.383	0.376
Canada	0.643	0.647	0.645	0.658	0.660	0.663	0.660	0.656	0.654	0.658	0.659
Denmark	0.476	0.462	0.445	0.446	0.445	0.435	0.419	0.402	0.398	0.401	0.390
Finland	0.382	0.377	0.370	0.380	0.386	0.367	0.354	0.344	0.350	0.359	0.357
France	0.420	0.408	0.397	0.408	0.410	0.399	0.389	0.376	0.374	0.382	0.378
Germany	0.526	0.519	0.501	0.507	0.507	0.506	0.505	0.498	0.497	0.507	0.510
Greece	0.322	0.322	0.319	0.312	0.325	0.319	0.310	0.304	0.301	0.305	0.296
Iceland	0.459	0.444	0.431	0.443	0.444	0.431	0.428	0.416	0.412	0.425	0.424
India	0.165	0.161	0.158	0.161	0.168	0.166	0.168	0.168	0.161	0.166	0.170
Ireland	0.904	0.906	0.882	0.900	0.922	0.907	0.921	0.923	0.906	0.913	0.914
Italy	0.385	0.373	0.367	0.382	0.381	0.376	0.366	0.354	0.356	0.368	0.362
Japan	0.463	0.458	0.452	0.455	0.466	0.452	0.444	0.434	0.436	0.449	0.445
Korea, Rep.	0.185	0.177	0.176	0.182	0.187	0.185	0.184	0.182	0.181	0.181	0.181
Mexico	0.271	0.264	0.256	0.262	0.267	0.256	0.246	0.241	0.243	0.253	0.256
Netherlands	0.556	0.542	0.526	0.538	0.538	0.532	0.525	0.513	0.506	0.515	0.511
New Zealand	0.519	0.512	0.496	0.511	0.505	0.493	0.475	0.467	0.464	0.473	0.482
Norway	0.474	0.459	0.443	0.455	0.468	0.456	0.445	0.429	0.426	0.440	0.433
Portugal	0.269	0.264	0.261	0.263	0.256	0.249	0.242	0.231	0.229	0.235	0.232
Singapore	0.651	0.633	0.606	0.592	0.576	0.565	0.559	0.552	0.548	0.553	0.554
Spain	0.339	0.335	0.330	0.343	0.347	0.335	0.326	0.312	0.304	0.312	0.304
Sweden	0.463	0.445	0.430	0.442	0.450	0.430	0.409	0.392	0.389	0.397	0.389
Switzerland	0.692	0.676	0.651	0.659	0.636	0.614	0.610	0.594	0.590	0.609	0.612
Thailand	0.152	0.148	0.146	0.147	0.147	0.148	0.148	0.148	0.146	0.146	0.147
Turkey	0.147	0.145	0.139	0.144	0.149	0.149	0.145	0.138	0.134	0.134	0.133
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.1 (Cont'd)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Australia	0.526	0.526	0.530	0.530	0.523	0.524	0.521	0.526	0.524	0.528	0.536
Austria	0.391	0.382	0.359	0.352	0.347	0.341	0.335	0.332	0.336	0.345	0.339
Canada	0.635	0.627	0.633	0.632	0.621	0.615	0.610	0.607	0.602	0.596	0.595
Denmark	0.406	0.394	0.375	0.370	0.367	0.358	0.348	0.339	0.337	0.343	0.338
Finland	0.369	0.360	0.350	0.348	0.345	0.345	0.344	0.344	0.340	0.331	0.322
France	0.394	0.384	0.363	0.355	0.351	0.346	0.343	0.341	0.342	0.348	0.341
Germany	0.502	0.492	0.488	0.481	0.475	0.470	0.470	0.477	0.490	0.504	0.507
Greece	0.301	0.288	0.272	0.266	0.259	0.249	0.246	0.243	0.240	0.245	0.239
Iceland	0.437	0.413	0.392	0.383	0.383	0.386	0.371	0.360	0.356	0.359	0.343
India	0.169	0.169	0.169	0.169	0.168	0.166	0.169	0.171	0.174	0.175	0.178
Ireland	0.900	0.875	0.878	0.875	0.857	0.866	0.888	0.894	1.000	1.000	1.000
Italy	0.372	0.360	0.342	0.335	0.331	0.328	0.324	0.320	0.319	0.326	0.319
Japan	0.462	0.447	0.424	0.419	0.413	0.409	0.409	0.407	0.413	0.424	0.414
Korea, Rep.	0.191	0.191	0.184	0.183	0.186	0.189	0.191	0.191	0.196	0.205	0.204
Mexico	0.258	0.239	0.225	0.218	0.205	0.199	0.191	0.188	0.188	0.192	0.188
Netherlands	0.505	0.494	0.487	0.479	0.472	0.459	0.447	0.449	0.454	0.464	0.466
New Zealand	0.485	0.481	0.485	0.476	0.471	0.462	0.453	0.451	0.450	0.452	0.455
Norway	0.445	0.435	0.419	0.415	0.411	0.404	0.390	0.381	0.380	0.391	0.387
Portugal	0.240	0.231	0.214	0.210	0.209	0.210	0.212	0.213	0.215	0.222	0.218
Singapore	0.537	0.521	0.510	0.482	0.469	0.473	0.481	0.491	0.500	0.506	0.508
Spain	0.313	0.303	0.286	0.279	0.275	0.274	0.271	0.270	0.271	0.277	0.270
Sweden	0.402	0.390	0.373	0.364	0.359	0.355	0.347	0.341	0.339	0.340	0.331
Switzerland	0.604	0.586	0.575	0.568	0.555	0.538	0.525	0.524	0.529	0.531	0.528
Thailand	0.146	0.143	0.141	0.139	0.139	0.139	0.142	0.145	0.147	0.147	0.147
Turkey	0.138	0.134	0.128	0.126	0.126	0.127	0.123	0.119	0.123	0.123	0.122
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.1 (Cont'd)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Australia	0.539	0.537	0.538	0.537	0.534	0.535	0.532	0.522	0.522	0.522	0.523
Austria	0.332	0.325	0.322	0.317	0.309	0.304	0.299	0.296	0.299	0.298	0.295
Canada	0.593	0.591	0.588	0.580	0.574	0.572	0.571	0.569	0.564	0.563	0.559
Denmark	0.332	0.331	0.332	0.332	0.330	0.327	0.325	0.326	0.328	0.327	0.324
Finland	0.318	0.319	0.322	0.324	0.328	0.331	0.331	0.333	0.335	0.337	0.337
France	0.332	0.328	0.328	0.324	0.322	0.322	0.320	0.321	0.324	0.325	0.323
Germany	0.499	0.495	0.493	0.489	0.487	0.486	0.485	0.484	0.483	0.480	0.477
Greece	0.231	0.224	0.222	0.217	0.212	0.208	0.203	0.201	0.207	0.209	0.210
Iceland	0.338	0.331	0.325	0.322	0.316	0.313	0.307	0.303	0.308	0.304	0.301
India	0.179	0.180	0.180	0.179	0.173	0.172	0.169	0.165	0.165	0.163	0.167
Ireland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Italy	0.311	0.304	0.303	0.295	0.287	0.280	0.273	0.270	0.273	0.273	0.268
Japan	0.406	0.394	0.390	0.384	0.373	0.357	0.344	0.339	0.342	0.340	0.338
Korea, Rep.	0.204	0.204	0.208	0.207	0.203	0.188	0.189	0.190	0.193	0.198	0.197
Mexico	0.183	0.179	0.169	0.166	0.163	0.160	0.156	0.155	0.153	0.151	0.148
Netherlands	0.459	0.452	0.454	0.456	0.459	0.464	0.467	0.467	0.466	0.464	0.460
New Zealand	0.462	0.461	0.460	0.456	0.448	0.440	0.440	0.433	0.433	0.435	0.434
Norway	0.383	0.380	0.380	0.378	0.373	0.364	0.354	0.348	0.353	0.353	0.348
Portugal	0.211	0.205	0.206	0.203	0.200	0.197	0.194	0.191	0.194	0.193	0.188
Singapore	0.515	0.519	0.517	0.511	0.504	0.484	0.484	0.488	0.467	0.463	0.456
Spain	0.263	0.256	0.254	0.249	0.244	0.240	0.236	0.234	0.238	0.238	0.236
Sweden	0.325	0.326	0.329	0.327	0.325	0.326	0.327	0.329	0.331	0.333	0.332
Switzerland	0.518	0.505	0.496	0.488	0.482	0.477	0.471	0.472	0.471	0.470	0.466
Thailand	0.145	0.143	0.142	0.139	0.134	0.126	0.128	0.129	0.130	0.133	0.138
Turkey	0.123	0.115	0.116	0.115	0.114	0.111	0.103	0.103	0.098	0.101	0.101
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.2 Efficiency Index under weakly disposability of undesirable outputs √Ω

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Australia	0.785	0.776	0.767	0.773	0.768	0.766	0.758	0.749	0.754	0.734	0.721
Austria	0.698	0.704	0.709	0.718	0.737	0.752	0.759	0.760	0.760	0.768	0.753
Canada	0.794	0.777	0.783	0.800	0.776	0.775	0.776	0.783	0.785	0.767	0.774
Denmark	0.774	0.774	0.778	0.766	0.776	0.793	0.784	0.781	0.775	0.760	0.760
Finland	0.638	0.648	0.655	0.661	0.682	0.673	0.666	0.670	0.679	0.674	0.686
France	0.695	0.696	0.702	0.707	0.729	0.735	0.736	0.746	0.741	0.738	0.746
Germany	0.716	0.717	0.716	0.719	0.726	0.725	0.726	0.738	0.740	0.730	0.731
Greece	0.726	0.713	0.698	0.670	0.644	0.654	0.656	0.648	0.631	0.620	0.607
Iceland	0.776	0.780	0.779	0.788	0.806	0.824	0.842	0.846	0.842	0.850	0.860
India	0.378	0.365	0.374	0.373	0.350	0.355	0.363	0.347	0.317	0.318	0.317
Ireland	0.932	0.943	0.923	0.947	0.958	0.944	0.967	0.965	0.930	0.928	0.931
Italy	0.663	0.661	0.673	0.687	0.696	0.719	0.718	0.728	0.731	0.731	0.727
Japan	0.791	0.807	0.824	0.812	0.847	0.868	0.874	0.892	0.895	0.896	0.897
Korea, Rep.	0.544	0.543	0.538	0.553	0.521	0.525	0.544	0.523	0.480	0.475	0.464
Mexico	0.639	0.647	0.660	0.674	0.617	0.610	0.613	0.563	0.542	0.526	0.523
Netherlands	0.764	0.752	0.756	0.766	0.782	0.787	0.783	0.785	0.769	0.761	0.756
New Zealand	0.825	0.827	0.833	0.852	0.845	0.840	0.813	0.822	0.827	0.811	0.818
Norway	0.807	0.807	0.813	0.819	0.855	0.881	0.883	0.880	0.878	0.870	0.867
Portugal	0.337	0.338	0.348	0.348	0.324	0.321	0.322	0.311	0.315	0.312	0.322
Singapore	0.723	0.672	0.688	0.700	0.657	0.622	0.633	0.616	0.620	0.659	0.710
Spain	0.706	0.691	0.711	0.725	0.642	0.652	0.651	0.667	0.638	0.631	0.621
Sweden	0.758	0.755	0.758	0.765	0.793	0.788	0.770	0.788	0.780	0.787	0.780
Switzerland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Thailand	0.513	0.490	0.497	0.505	0.494	0.489	0.506	0.490	0.472	0.462	0.470
Turkey	0.564	0.548	0.542	0.553	0.521	0.530	0.533	0.531	0.509	0.504	0.483
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.2 (Cont'd)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Australia	0.701	0.721	0.706	0.715	0.716	0.709	0.704	0.699	0.672	0.712	0.687
Austria	0.767	0.790	0.773	0.776	0.787	0.784	0.793	0.787	0.789	0.800	0.817
Canada	0.764	0.764	0.756	0.779	0.792	0.786	0.771	0.770	0.757	0.784	0.750
Denmark	0.768	0.786	0.784	0.765	0.781	0.773	0.784	0.788	0.783	0.767	0.791
Finland	0.716	0.734	0.733	0.718	0.715	0.709	0.733	0.737	0.728	0.709	0.705
France	0.764	0.783	0.782	0.784	0.801	0.809	0.821	0.814	0.819	0.821	0.833
Germany	0.730	0.733	0.720	0.725	0.730	0.729	0.731	0.743	0.757	0.821	0.815
Greece	0.603	0.599	0.593	0.589	0.593	0.574	0.572	0.561	0.558	0.579	0.565
Iceland	0.878	0.878	0.858	0.872	0.887	0.909	0.887	0.864	0.856	0.874	0.857
India	0.318	0.325	0.322	0.319	0.321	0.318	0.322	0.319	0.322	0.322	0.321
Ireland	0.933	0.911	0.902	0.907	0.868	0.866	0.888	0.894	1.000	1.000	1.000
Italy	0.732	0.746	0.743	0.743	0.758	0.756	0.763	0.754	0.753	0.764	0.760
Japan	0.913	0.928	0.915	0.931	0.945	0.954	0.957	0.957	0.965	0.987	0.982
Korea, Rep.	0.464	0.495	0.481	0.468	0.499	0.498	0.482	0.472	0.483	0.497	0.501
Mexico	0.512	0.506	0.504	0.518	0.522	0.501	0.498	0.478	0.465	0.472	0.473
Netherlands	0.781	0.791	0.775	0.769	0.790	0.786	0.793	0.770	0.781	0.805	0.801
New Zealand	0.814	0.831	0.817	0.793	0.781	0.768	0.751	0.734	0.744	0.752	0.729
Norway	0.871	0.906	0.904	0.906	0.926	0.917	0.911	0.879	0.890	0.914	0.933
Portugal	0.319	0.311	0.294	0.293	0.291	0.290	0.297	0.312	0.336	0.361	0.350
Singapore	0.690	0.659	0.672	0.668	0.654	0.688	0.685	0.682	0.654	0.702	0.688
Spain	0.625	0.637	0.638	0.634	0.671	0.663	0.667	0.653	0.660	0.668	0.664
Sweden	0.799	0.822	0.829	0.819	0.832	0.841	0.842	0.838	0.882	0.855	0.858
Switzerland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Thailand	0.473	0.479	0.462	0.455	0.471	0.448	0.434	0.408	0.400	0.377	0.378
Turkey	0.461	0.472	0.467	0.441	0.440	0.434	0.463	0.417	0.430	0.432	0.446
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.2 (Cont'd)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Australia	0.678	0.670	0.675	0.668	0.657	0.651	0.641	0.640	0.637	0.642	0.648
Austria	0.809	0.811	0.814	0.802	0.794	0.796	0.818	0.816	0.815	0.804	0.792
Canada	0.732	0.745	0.745	0.730	0.701	0.717	0.715	0.714	0.720	0.692	0.676
Denmark	0.767	0.772	0.779	0.763	0.791	0.801	0.829	0.842	0.846	0.838	0.811
Finland	0.680	0.668	0.676	0.671	0.686	0.706	0.716	0.733	0.726	0.707	0.691
France	0.822	0.836	0.841	0.813	0.824	0.816	0.836	0.834	0.842	0.837	0.837
Germany	0.803	0.803	0.804	0.804	0.801	0.801	0.808	0.808	0.808	0.802	0.795
Greece	0.553	0.547	0.549	0.537	0.532	0.532	0.542	0.535	0.548	0.548	0.555
Iceland	0.841	0.848	0.844	0.828	0.839	0.856	0.881	0.869	0.897	0.870	0.880
India	0.320	0.322	0.329	0.325	0.323	0.323	0.324	0.318	0.326	0.319	0.324
Ireland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Italy	0.754	0.758	0.765	0.745	0.738	0.734	0.741	0.737	0.751	0.740	0.733
Japan	0.977	0.964	0.967	0.954	0.942	0.934	0.929	0.916	0.929	0.914	0.916
Korea, Rep.	0.500	0.506	0.524	0.510	0.505	0.499	0.513	0.512	0.522	0.528	0.531
Mexico	0.479	0.478	0.462	0.475	0.484	0.490	0.489	0.484	0.497	0.490	0.481
Netherlands	0.786	0.805	0.813	0.795	0.807	0.811	0.825	0.830	0.839	0.808	0.820
New Zealand	0.744	0.743	0.750	0.727	0.702	0.703	0.699	0.685	0.686	0.689	0.691
Norway	0.922	0.935	0.950	1.000	1.000	1.000	0.991	0.987	0.987	0.868	0.930
Portugal	0.334	0.331	0.333	0.331	0.329	0.341	0.347	0.356	0.358	0.355	0.347
Singapore	0.665	0.637	0.650	0.718	0.680	0.687	0.698	0.718	0.705	0.706	0.743
Spain	0.664	0.661	0.667	0.649	0.643	0.649	0.653	0.649	0.665	0.651	0.654
Sweden	0.861	0.856	0.871	0.843	0.902	0.911	0.934	0.911	0.941	0.877	0.891
Switzerland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Thailand	0.362	0.359	0.375	0.334	0.329	0.328	0.319	0.312	0.317	0.306	0.306
Turkey	0.434	0.428	0.442	0.408	0.416	0.415	0.399	0.379	0.400	0.395	0.394
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.3 Environmental Efficiency Index H=$\sqrt{\Gamma}/\sqrt{\Omega}$

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Australia	0.708	0.701	0.679	0.681	0.695	0.694	0.693	0.702	0.696	0.729	0.749
Austria	0.592	0.575	0.555	0.566	0.554	0.529	0.516	0.490	0.492	0.498	0.500
Canada	0.809	0.833	0.824	0.823	0.851	0.856	0.850	0.838	0.832	0.857	0.851
Denmark	0.615	0.597	0.571	0.582	0.573	0.549	0.534	0.515	0.514	0.528	0.513
Finland	0.598	0.581	0.565	0.575	0.566	0.546	0.531	0.514	0.515	0.533	0.521
France	0.605	0.586	0.566	0.577	0.563	0.542	0.528	0.504	0.504	0.517	0.506
Germany	0.734	0.724	0.700	0.705	0.698	0.698	0.695	0.675	0.671	0.694	0.699
Greece	0.444	0.452	0.457	0.466	0.505	0.488	0.473	0.470	0.477	0.492	0.487
Iceland	0.591	0.569	0.553	0.563	0.551	0.523	0.508	0.491	0.490	0.500	0.493
India	0.437	0.442	0.424	0.430	0.479	0.467	0.462	0.486	0.507	0.521	0.534
Ireland	0.970	0.960	0.956	0.950	0.962	0.961	0.952	0.956	0.974	0.985	0.982
Italy	0.582	0.565	0.545	0.556	0.548	0.523	0.509	0.487	0.487	0.503	0.498
Japan	0.585	0.568	0.549	0.560	0.550	0.521	0.508	0.487	0.487	0.501	0.496
Korea, Rep.	0.340	0.326	0.327	0.329	0.359	0.353	0.339	0.347	0.378	0.380	0.390
Mexico	0.424	0.408	0.387	0.389	0.433	0.420	0.401	0.428	0.448	0.482	0.489
Netherlands	0.727	0.720	0.696	0.703	0.689	0.676	0.670	0.654	0.658	0.677	0.677
New Zealand	0.629	0.619	0.596	0.600	0.598	0.586	0.584	0.569	0.561	0.583	0.589
Norway	0.587	0.569	0.545	0.555	0.547	0.518	0.504	0.487	0.485	0.506	0.500
Portugal	0.798	0.779	0.751	0.754	0.791	0.777	0.753	0.742	0.728	0.753	0.720
Singapore	0.901	0.943	0.881	0.845	0.876	0.907	0.883	0.895	0.883	0.839	0.779
Spain	0.479	0.484	0.464	0.473	0.541	0.514	0.500	0.468	0.477	0.494	0.490
Sweden	0.611	0.589	0.567	0.577	0.568	0.546	0.531	0.498	0.499	0.504	0.499
Switzerland	0.692	0.676	0.651	0.659	0.636	0.614	0.610	0.594	0.590	0.609	0.612
Thailand	0.296	0.302	0.293	0.290	0.298	0.304	0.293	0.302	0.309	0.317	0.312
Turkey	0.262	0.264	0.256	0.260	0.287	0.281	0.272	0.261	0.263	0.265	0.275
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.3 (Cont'd)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Australia	0.750	0.730	0.750	0.740	0.730	0.740	0.740	0.752	0.780	0.742	0.781
Austria	0.510	0.484	0.464	0.453	0.440	0.435	0.423	0.422	0.426	0.431	0.415
Canada	0.831	0.821	0.838	0.811	0.784	0.782	0.790	0.788	0.795	0.760	0.793
Denmark	0.528	0.501	0.479	0.483	0.470	0.463	0.444	0.430	0.430	0.448	0.428
Finland	0.516	0.490	0.477	0.484	0.482	0.487	0.469	0.467	0.467	0.468	0.457
France	0.516	0.490	0.464	0.453	0.438	0.428	0.418	0.419	0.418	0.424	0.410
Germany	0.689	0.671	0.678	0.663	0.650	0.644	0.643	0.643	0.648	0.614	0.622
Greece	0.500	0.480	0.458	0.451	0.437	0.434	0.430	0.433	0.430	0.424	0.422
Iceland	0.498	0.471	0.457	0.440	0.431	0.425	0.419	0.416	0.416	0.410	0.400
India	0.531	0.521	0.526	0.529	0.523	0.522	0.523	0.537	0.542	0.543	0.554
Ireland	0.966	0.961	0.973	0.964	0.987	1.000	1.000	1.000	1.000	1.000	1.000
Italy	0.508	0.483	0.460	0.451	0.437	0.433	0.424	0.424	0.424	0.426	0.419
Japan	0.506	0.481	0.463	0.450	0.437	0.429	0.427	0.426	0.428	0.429	0.422
Korea, Rep.	0.410	0.386	0.383	0.390	0.372	0.380	0.397	0.404	0.406	0.413	0.408
Mexico	0.504	0.473	0.447	0.420	0.393	0.397	0.385	0.393	0.405	0.406	0.397
Netherlands	0.647	0.624	0.628	0.623	0.597	0.584	0.564	0.582	0.581	0.576	0.581
New Zealand	0.596	0.579	0.594	0.600	0.603	0.602	0.602	0.614	0.605	0.601	0.624
Norway	0.511	0.480	0.464	0.458	0.444	0.441	0.428	0.433	0.427	0.427	0.414
Portugal	0.752	0.742	0.728	0.717	0.718	0.725	0.712	0.683	0.640	0.616	0.623
Singapore	0.778	0.790	0.759	0.722	0.716	0.687	0.701	0.720	0.764	0.722	0.739
Spain	0.502	0.476	0.448	0.440	0.410	0.414	0.407	0.413	0.411	0.414	0.407
Sweden	0.503	0.475	0.450	0.445	0.432	0.422	0.412	0.407	0.384	0.398	0.385
Switzerland	0.604	0.586	0.575	0.568	0.555	0.538	0.525	0.524	0.529	0.531	0.528
Thailand	0.308	0.299	0.307	0.307	0.294	0.311	0.327	0.356	0.367	0.391	0.388
Turkey	0.298	0.284	0.275	0.285	0.286	0.293	0.267	0.286	0.285	0.285	0.275
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.3 (Cont'd)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Australia	0.795	0.802	0.798	0.803	0.812	0.822	0.829	0.816	0.820	0.812	0.807
Austria	0.410	0.401	0.395	0.395	0.389	0.382	0.366	0.363	0.366	0.371	0.373
Canada	0.810	0.794	0.789	0.794	0.819	0.798	0.799	0.797	0.784	0.814	0.827
Denmark	0.433	0.428	0.426	0.434	0.417	0.408	0.392	0.387	0.387	0.390	0.400
Finland	0.468	0.477	0.477	0.483	0.479	0.468	0.462	0.454	0.461	0.477	0.488
France	0.404	0.393	0.390	0.399	0.390	0.394	0.383	0.385	0.385	0.388	0.386
Germany	0.622	0.617	0.613	0.609	0.608	0.607	0.600	0.599	0.598	0.599	0.600
Greece	0.418	0.410	0.404	0.404	0.398	0.390	0.375	0.377	0.377	0.382	0.378
Iceland	0.401	0.391	0.385	0.389	0.377	0.366	0.349	0.349	0.344	0.349	0.342
India	0.558	0.559	0.547	0.550	0.536	0.532	0.522	0.519	0.506	0.512	0.515
Ireland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Italy	0.412	0.401	0.396	0.396	0.389	0.381	0.368	0.366	0.364	0.369	0.366
Japan	0.416	0.409	0.404	0.403	0.396	0.382	0.370	0.371	0.368	0.372	0.369
Korea, Rep.	0.409	0.403	0.397	0.407	0.402	0.377	0.368	0.371	0.370	0.375	0.371
Mexico	0.383	0.375	0.365	0.350	0.338	0.326	0.318	0.320	0.308	0.309	0.307
Netherlands	0.584	0.562	0.559	0.574	0.569	0.571	0.566	0.563	0.556	0.573	0.561
New Zealand	0.621	0.620	0.614	0.628	0.637	0.626	0.630	0.631	0.632	0.631	0.629
Norway	0.416	0.406	0.400	0.378	0.373	0.364	0.357	0.353	0.358	0.407	0.374
Portugal	0.633	0.619	0.617	0.614	0.606	0.578	0.558	0.538	0.541	0.544	0.543
Singapore	0.774	0.815	0.795	0.712	0.741	0.705	0.693	0.679	0.662	0.656	0.614
Spain	0.396	0.387	0.381	0.384	0.379	0.370	0.362	0.361	0.358	0.366	0.361
Sweden	0.378	0.381	0.378	0.388	0.360	0.358	0.350	0.361	0.352	0.380	0.372
Switzerland	0.518	0.505	0.496	0.488	0.482	0.477	0.471	0.472	0.471	0.470	0.466
Thailand	0.401	0.398	0.378	0.415	0.406	0.383	0.399	0.414	0.410	0.435	0.451
Turkey	0.285	0.269	0.262	0.282	0.274	0.266	0.258	0.271	0.246	0.254	0.255
UK	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
USA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7.3.1 Geometric Mean of Environmental Efficiency Index H=√Γ/√Ω

	1971-1979	1980-1989	1990-1999	2000-2003	Geo. Mean
Australia	0.694	0.741	0.796	0.814	**0.753**
Austria	0.540	0.462	0.401	0.368	**0.449**
Canada	0.835	0.815	0.795	0.805	**0.813**
Denmark	0.560	0.483	0.424	0.391	**0.471**
Finland	0.554	0.492	0.470	0.470	**0.499**
France	0.552	0.463	0.400	0.386	**0.455**
Germany	0.700	0.667	0.616	0.599	**0.651**
Greece	0.470	0.460	0.407	0.379	**0.435**
Iceland	0.537	0.454	0.388	0.346	**0.438**
India	0.459	0.527	0.544	0.513	**0.511**
Ireland	0.960	0.982	1.000	1.000	**0.983**
Italy	0.533	0.461	0.401	0.366	**0.447**
Japan	0.534	0.461	0.405	0.370	**0.449**
Korea, Rep.	0.344	0.389	0.399	0.372	**0.377**
Mexico	0.415	0.436	0.365	0.311	**0.391**
Netherlands	0.688	0.619	0.572	0.563	**0.615**
New Zealand	0.593	0.596	0.621	0.631	**0.607**
Norway	0.532	0.466	0.395	0.372	**0.447**
Portugal	0.763	0.725	0.610	0.541	**0.673**
Singapore	0.890	0.748	0.745	0.652	**0.770**
Spain	0.488	0.448	0.389	0.361	**0.428**
Sweden	0.553	0.454	0.376	0.366	**0.441**
Switzerland	0.635	0.569	0.502	0.470	**0.551**
Thailand	0.299	0.313	0.392	0.427	**0.344**
Turkey	0.267	0.281	0.274	0.257	**0.272**
UK	1.000	1.000	1.000	1.000	**1.000**
USA	1.000	1.000	1.000	1.000	**1.000**
Geo. Mean	**0.576**	**0.545**	**0.510**	**0.471**	**0.535**

Table 7.4 Output Loss from Imposing Weak Disposability of Pollutants

(1-H)×GDP (billions US $)

	1971-1979	1980-1989	1990-1999	2000-2003	Mean
Australia	55	56	57	57	**67**
Austria	48	51	53	55	**78**
Canada	57	57	59	60	**93**
Denmark	43	45	46	47	**65**
Finland	28	30	31	32	**44**
France	327	345	361	375	**544**
Germany	325	338	349	356	**502**
Greece	38	39	40	40	**51**
Iceland	2	2	2	2	**3**
India	71	72	73	74	**127**
Ireland	1	1	1	1	**1**
Italy	286	303	319	331	**468**
Japan	1071	1139	1202	1254	**1932**
Korea, Rep.	60	64	68	71	**164**
Mexico	144	153	161	167	**239**
Netherlands	65	67	70	72	**106**
New Zealand	13	14	14	14	**16**
Norway	34	37	39	40	**63**
Portugal	12	13	14	14	**25**
Singapore	2	2	2	3	**10**
Spain	151	155	159	161	**234**
Sweden	66	69	71	74	**104**
Switzerland	61	63	65	66	**91**
Thailand	19	20	21	23	**46**
Turkey	55	57	59	61	**92**
UK	0	0	0	0	**0**
USA	0	0	0	0	**0**
Mean	**195**	**277**	**399**	**501**	**314**

Table 7.5 Pooled OLS Results:

Variables	Model 1	Model 2	Model 3	Model 4
GDP_i	0.891***	0.891***	0.866***	0.866***
	[0.005]	[0.076]	[0.005]	[0.078]
GDP_j	0.838***	0.838***	0.821***	0.821***
	[0.005]	[0.036]	[0.005]	[0.038]
$Dist_{ij}$	-0.870***	-0.870***	-0.882***	-0.882***
	[0.008]	[0.077]	[0.008]	[0.071]
EFI_i	_	_	0.792***	0.792**
	_	_	[0.023]	[0.380]
EFI_j	_	_	0.641***	0.641***
	_	_	[0.022]	[0.081]
Constant	-8.375***	-8.375***	-6.859***	-6.859***
	[0.118]	[0.948]	[0.118]	[1.020]
R^2	0.733	0.733	0.754	0.754
Adj R^2	0.733	_	0.754	_
Observations	22918	22918	22918	22918

The dependent variable is the bilateral exports of countryi to j
Standard errors are provided in brackets
Model 1 - Pooled OLS results of Simple Gravity Model
Model 2 - Pooled OLS results of Simple Gravity Model with White's heteroscedasticity consistent (robust) clustered standard errors
Model 3 - Pooled OLS results of Simple Gravity Model with Environmental Efficiency Index
Model 4 - Pooled OLS results of Simple Gravity Model with Environmental Efficiency Index and White's heteroskedasticity consistent (robust) clustered standard errors
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7.6 Estimated Models with Country Fixed Effect

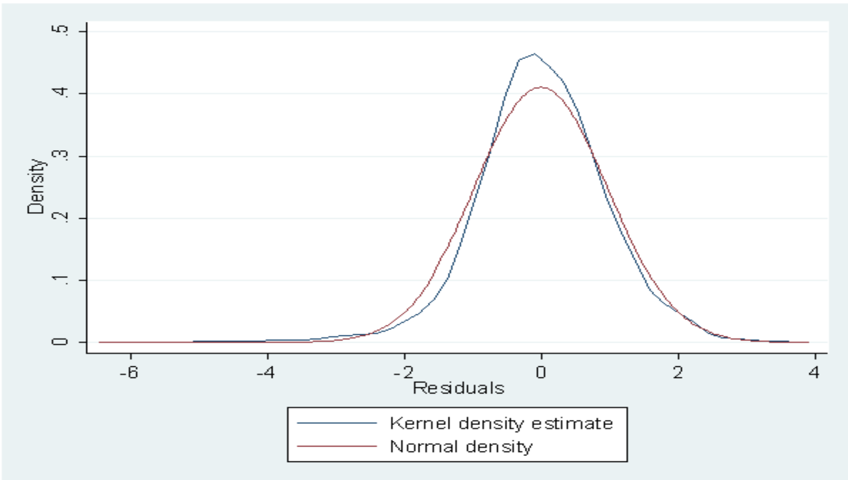
Variables	Model 1	Model 2	Model 3	Model 4
GDP_i	1.379***	1.379***	1.527***	1.527***
	[0.020]	[0.116]	[0.020]	[0.141]
GDP_j	0.818***	0.818***	0.777***	0.777***
	[0.004]	[0.036]	[0.004]	[0.035]
$Dist_{ij}$	-0.915***	-0.915***	-0.927***	-0.927***
	[0.008]	[0.064]	[0.007]	[0.066]
EFI_i	_	_	-0.209***	-0.209
	_	_	[0.063]	[0.307]
EFI_j	_	_	0.827***	0.827***
	_	_	[0.019]	[0.082]
Constant	-13.366***	-13.366***	-14.122***	-14.122***
	[0.254]	[1.557]	[0.256]	[1.790]
R^2	0.828	0.828	0.841	0.841
Adj R^2	0.828	_	0.841	_
Observations	22918	22918	22918	22918

The dependent variable is the bilateral exports of country i to j
Standard errors are provided in brackets
Model 1 - Simple Gravity Model with Country Fixed Effect
Model 2 - Simple Gravity Model with White's heteroskedasticity consistent (robust) clustered standard errors with Country Fixed Effect
Model 3 - Simple Gravity Model with Environmental Efficiency Index and Country Fixed Effect
Model 4 - Simple Gravity Model with Environmental Efficiency Index and White's heteroskedasticity consistent (robust) clustered standard errors with Country Fixed Effect
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7.7 Diagnostic Test Results

	Test Stat	p-value
White Test for Heteroscedasticity	χ^2=2504.66	0.00000
Wooldridge Test for Autocorrelation	F=181.92	0.00000
Hausmann Test for model definiton	χ^2=249.00	0.00000

Variable	**VIF**	**1/VIF**
lei	1.04	0.95845
lej	1.04	0.959699
lyi	1.04	0.960362
lyj	1.04	0.961938
ldist	1.01	0.994301



Simple Gravity Model with Environmental Efficiency and Country Fixed Effect model represented in Table 7.6 column (3) is used in Diagnostic Tests.
The null hypothesis of the White test is that the variance of the disturbance term is homoscedastic.
The null hypothesis of the Wooldridge serial correlation test is that that there is no first order serial correlation.
The null hypothesis of the Hausmann test is that random effect is consistent but fixed effect is not.

Table 7.8 Extension of the Model

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GDP_i	1.527***	1.568***	1.485***	1.488***	1.476***	1.476***
	[0.141]	[0.268]	[0.135]	[0.135]	[0.137]	[0.137]
GDP_j	0.777***	0.791***	0.829***	0.826***	0.828***	0.827***
	[0.035]	[0.045]	[0.039]	[0.040]	[0.040]	[0.041]
$Dist_{ij}$	-0.927***	-0.922***	-0.879***	-0.800***	-0.801***	-0.797***
	[0.066]	[0.066]	[0.066]	[0.080]	[0.077]	[0.100]
EFI_i	-0.209	-0.182	-0.160	-0.162	-0.148	-0.148
	[0.307]	[0.339]	[0.312]	[0.314]	[0.311]	[0.312]
EFI_j	0.827***	0.811***	0.801***	0.805***	0.736***	0.735***
	[0.082]	[0.094]	[0.082]	[0.078]	[0.074]	[0.078]
Pop_i	_	-0.183	_	_	_	_
	_	[0.891]	_	_	_	_
Pop_j	_	-0.016	_	_	_	_
	_	[-0.047]	_	_	_	_
$Land_i$	_	_	-0.386***	-0.394***	-0.406***	-0.406***
	_	_	[0.039]	[0.039]	[0.039]	[0.040]
$Land_j$	_	_	-0.088***	-0.097***	-0.112***	-0.112***
	_	_	[0.019]	[0.019]	[0.019]	[0.021]
A_{ij}	_	_	_	0.521***	0.333**	0.334**
	_	_	_	[0.150]	[0.152]	[0.155]
$Lang_{ij}$	_	_	_	_	0.545***	0.548***
	_	_	_	_	[0.129]	[0.120]
EU_{ij}	_	_	_	_	_	0.017
	_	_	_	_	_	[0.166]
Constant	-14.122***	-11.555	-7.464***	-7.969***	-7.617***	-7.652***
	[1.790]	[12.035]	[1.152]	[1.161]	[1.181]	[1.301]
R^2	0.841	0.841	0.843	0.846	0.848	0.848
Adj R^2	_	_	_	_	_	_
Observations	22918	22918	22918	22918	22918	22918

The dependent variable is the bilateral exports of country i to j
White's heteroskedasticity consistent (robust) clustered standard errors are provided in brackets and there are country fixed effects in all models.
Model 1 - Results of Simple Gravity Model with Environmental Efficiency
Model 2 - Results of Simple Gravity Model with Population
Model 3 - Results of Simple Gravity Model with Land
Model 4 - Results of Simple Gravity Model with Land and Adjacent dummy variables
Model 5- Results of Simple Gravity Model with Land, Adjacent and Language dummy variables
Model 6- Results of Simple Gravity Model with Land, Adjacent, Language and European Union dummy variables
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7.9 Estimated Models with Random Effects

Variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**
GDP_i	1.300***	1.300***	1.337***	1.337***
	[0.015]	[0.018]	[0.017]	[0.020]
GDP_j	0.939***	0.939***	0.931***	0.931***
	[0.014]	[0.016]	[0.014]	[0.017]
$Dist_{ij}$	-0.916***	-0.916***	-0.918***	-0.918***
	[0.038]	[0.033]	[0.036]	[0.032]
EFI_i	_	_	0.038	0.038
	_	_	[0.038]	[0.045]
EFI_j	_	_	0.158***	0.158***
	_	_	[0.037]	[0.044]
Constant	-13.868***	-13.868***	-14.099***	-14.099***
	[0.423]	[1.551]	[0.407]	[0.411]
R^2	0.825	0.825	0.829	0.829
Adj R^2	_	_	_	_
Observations	22918	22918	22918	22918

The dependent variable is the bilateral exports of country i to j
Standard errors are provided in brackets
Model 1 - Simple Gravity Model with Country Random Effect
Model 2 - Simple Gravity Model with White's heteroskedasticity consistent (robust) standard errors with Country Random Effect
Model 3 - Simple Gravity Model with Environmental Efficiency Index with Country Random Effect
Model 4 - Simple Gravity Model with Environmental Efficiency Index and White's heteroskedasticity consistent (robust) standard errors with Country Random Effect
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7.10 Estimated Models with Instrumental Variables

Variables	Model 1	Model 2	Model 3
$GDP_{i(-5)}$	1.418***	1.536***	1.488***
	[0.127]	[0.153]	[0.144]
$GDP_{j(-5)}$	0.805***	0.766***	0.821***
	[0.034]	[0.033]	[0.037]
$Dist_{ij}$	-0.896***	-0.915***	-0.780***
	[0.064]	[0.066]	[0.078]
EFI_i	_	-0.376	-0.314
	_	[0.344]	[0.347]
EFI_j	_	0.804***	0.728***
	_	[0.079]	[0.071]
$Land_i$	_	_	-0.454***
	_	_	[0.045]
$Land_j$	_	_	-0.119***
	_	_	[0.019]
A_{ij}	_	_	0.377**
	_	_	[0.154]
$Lang_{ij}$	_	_	0.496***
	_	_	[0.123]
Constant	-13.624***	-13.995	-6.794***
	[1.689]	[1.950]	[1.218]
R^2	0.826	0.839	0.847
Adj R^2	_	_	_
Observations	19553	19553	19553

The dependent variable is the bilateral exports of country i to j White's heteroskedasticity consistent (robust) clustered standard errors are provided in brackets and there are country fixed effects in all models.
Model 1 - Simple Gravity Model
Model 2 - Simple Gravity Model with Environmental Efficiency Index
Model 3 - Extended Gravity Model with Environmental Efficiency Index
* significant at 10%; ** significant at 5%; *** significant at 1%.

Table 7.11 Relative Efficiency under H_0:β_4=β_5

Variables	Model 1	Model 3
GDP_i	1.455***	1.408***
	[0.136]	[0.128]
GDP_j	0.776***	0.827***
	[0.035]	[0.040]
$Dist_{ij}$	-0.926***	-0.801***
	[0.066]	[0.077]
EFI_j/EFI_i	0.785***	0.695***
	[0.072]	[0.061]
$Land_i$	_	-0.388***
	_	[0.038]
$Land_j$	_	-0.112***
	_	[0.019]
A_{ij}	_	0.329**
	_	[0.154]
$Lang_{ij}$	_	0.557***
	_	[0.130]
Constant	-13.406***	-7.215***
	[1.819]	[1.199]
R^2	0.840	0.848
Adj R^2	_	_
Observations	22918	22918

The dependent variable is the bilateral exports of country i to j White's heteroskedasticity consistent (robust) clustered standard errors are provided in brackets and there are country fixed effects in all models.
Model 1 - Simple Gravity Model with Environmental Efficiency Index
Model 2 - Extended Gravity Model with Environmental Efficiency Index
* significant at 10%; ** significant at 5%; *** significant at 1%.