STRATEGIC OUTPUT AND GREEN TECHNOLOGY RIVALRY IN A GLOBALIZED WORLD:
THEORY, EMPIRICS AND POLICY IMPLICATION

A Thesis

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ABSTRACT

The concerns over deteriorating global climate change have been leading to the creation of several global initiatives, such as the Climate Change Convention and Kyoto Protocol. However, the effects of those globally coordinated initiatives have been doubted since their advent, and research on the effectiveness of those efforts has been a focus of global attention. The purpose of this paper is to examine the nature of the commons that arise from climate changes, and investigate to what extent current market incentives perform to reduce the emission of greenhouse gases. The paper empirically assesses the factors and conditions that affect the market incentives in the current environment, and intends to provide an insight into the future international scheme for coordinated efforts.

The basic premise of the paper is that the development of technology to stop global warming can serve as an incentive in and of itself. We develop this technology driven approach in the framework of an open economy in which there exists strong domestic political pressure for economic growth. This paper begins by examining the needs to develop technology for the reduction of carbon emissions. Following this discussion the paper presents a theoretical model to examine if the desire for growth through international trade encourages investment in technology, and examines how this induced level of investment relates to the globally efficient level of investment. Finally, the paper empirically investigates some of the determinants of technology investment using cross country panel data over time.

In our theoretical model we derive propositions that the level of technology depends on the degree of openness, the cost of developing green technology and the importance which a country places on material growth and a clean environment (the weights associated with these items in a country's welfare function). Through our

empirical studies, we first examine the potential explanatory variables that affect both welfare weights and technology development cost, and then choose the level of income, unemployment rate, degree of openness, number of ratified major environmental conventions, degree of democracy and regional peer effect as a set of important socio-economic explanatory variables that influence the level of technology. Our theoretical derivations suggest that the degree of openness has a positive effect on stimulating investment in clean technology, while factors affecting the welfare weight on material progress are likely to have a negative effect. The factors affecting the development costs also need careful attention. We can summarize our empirical findings as follows.

First, we find the degree of openness is related to the degree of the green technology development. We find that countries that have been under high growth pressure do not necessarily confirm this relationship. However, when we consider the different openness measurement, the Sachs and Warner openness measure, it seems that degree of openness is positively related to the development of green technology.. Second, we find that unemployment rate has negative influence on developing green technology and the degree of influence depends on the stage of economic development. Third, we find that the degree of democracy has different effect on developing green technology for countries with different level of income. For example, we find that the degree of democracy for high income countries has a negative effect on the technology investment. However, in highly developing countries, we find positive effects. Fourth, we show that there are regional peer efforts on developing the green technology in certain regions. For instance, we find that the European region with shared cultural heritage shows a positive peer effect on developing the green technology. However, we find the opposite effect for the North American Region. Fifth, we find that two most recent conventions such as the UNFCCC and the Kyoto protocol have positive effects on developing the technology. This implies that the exogenously given welfare weight on environment through the major convention dummies that countries have signed and ratified affects the development of technology in a positive way.

Finally, the policy implications from our examinations are not straightforward. In the absence of coordinated efforts, each country has different incentives for the investment in clean technology and the incentive compatible mechanism to allocate the burden of developing world optimum technology would be extremely difficult. Those countries with certain favorable characteristics with the high degree of openness, low development cost and greater revealed preference for clean environment may lead the investment while the rest of the world follows leaders' initiatives. These propositions however need further scrutiny and research in the future.

BIOGRAPHICAL SKETCH

Sang Won Yoon was born in Seoul, South Korea. He attended the Korea University for his undergraduate studies in Economics. Prior to coming to Cornell University for pursuing his Master degree, he had served as a KATUSA (Korean Augmentation To the United States Army) and honorably discharged receiving Army Commendation Medal.

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CHAPTER 1

INTRODUCTION

1.1 Background and the Scope of Thesis

Most problems of public goods, both at a domestic and global level, are created when there is a failure to meet the socially optimal supply of public goods. A free-riding issue has been considered a major limitation of public goods and this free-riding problem arises because there is an incentive obtained by doing so, resulting in a failure to meet the supply level. In this respect, a government is mostly a major supplier of domestic public goods. As an example, national security of one country is a public good in that it has characteristics of non-rivalry and non-excludability. A person in the country cannot be excluded from the national security service provided by the suppliers and no one has to compete with others for the service. Therefore, in most countries, a government is in charge of supplying the national security service by collecting taxes from taxpayers and providing it according to the necessity of the service. Here one question arises. Who should be a supplier of the commons[1] such as fresh air, which exists and moves trans-nationally?[2] In other words, if air was polluted beyond the capacity to purify, who should be responsible for cleaning up the air? In addition, what if one or more countries make an effort to recover the polluted commons, but other free-riders just enjoy the result and deteriorate the air for their own interests with the expectation that other countries will pick up the slack? How and

[1] The goods that have rivalry and non-excludability

[2] United Nations Development Programme (UNDP) refers to this type of public good as Global Public Good (GPG) and defines GPG as follows; “Goods ("things") whose characteristics of publicness (non-rivalry in consumption and non-excludability of benefits) extend to more than one set of countries or more than one geographic region and don't discriminate against any population groups or generations (present and future) are *global public goods.”*
UNDP refers ozone shield and atmosphere to as so-called “pre-existing" global public goods.
See http://www.undp.org/globalpublicgoods/Q-A/qa.pdf

who will manage those problems and control incentives of free-riding?

This paper focuses on climate change, a problem incurred due to the characteristics of the air as the commons. We first survey global efforts to solve this climate change problem in more detail and then present a theoretical model to provide better insights into the relationship between international trade and global warming. We derive some theoretical propositions on the incentives to develop clean technology in an open economy and explain how to test those propositions empirically. We also introduce a set of potentially important determinants of green technology investment and specify a testable model. A detailed explanation of empirical analysis is presented along with the direction of further research.

1.2 International Efforts on Climate Change

1.2.1 The Creation of United Nations Framework Convention on Climate Change

Controversy among scholars has arisen over the problem of climate change. Since this climate change is closely linked to the overall viability of living things on earth, this issue of who and how to clean and maintain this global public good-air, has been the center of attention with several different proposals and responses. However, most scholars have agreed on the need for more effective, globally cooperative responses to the issue.

In fact, it was the early 1970s when environmental issues soared as a significant agenda for countries, especially for developed ones. In 1972, the Rome Club pointed out the significance of environmental conservation by publishing the report, “The Limits of Growth.” This report led, in 1988, to the creation of the World

Meteorological Organization and the United Nations Environment Program. Meanwhile, the Intergovernmental Panel on Climate Change (IPCC) has begun its activities under concerns of scientific evidence regarding global warming (Roh (2005)). The United Nations Framework Convention on Climate Change, which was initiated in 1992 as one of the agreements through which countries are banding together to solve the global warming problem, entered into force on 21 March 1994.[3] The Convention on Climate Change sets an overall framework for intergovernmental efforts to curb the challenge posed by climate change (UNFCCC (2006a)).

In line with the consideration of economic development level and historical amount of CO2 emissions, UNFCCC tried to divide countries into several groups that share similar interests and situations. However, dividing the world into two groups-developed and developing countries-for setting up rules for each group is much riskier than one might guess. This is because almost every country has different interests including varying economic and political concerns such that reaching consensus would become a huge time-consuming or perhaps never-ending task. Despite this obstacle, UNFCCC classifies its signatories into three groups; Annex 1[4] (industrialized countries), Annex 2[5] (developed countries which pay for costs of developing countries) and Non-Annex 1.

Even though the Convention was successful in the respect that it made the world recognize the global climate change problem making 188 countries join as of

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[3] As of November 2006, 189 Parties had ratified the Convention.

[4] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America

[5] Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States of America

today (Barrett (2003)), it could not suffice for the purpose of reducing actual greenhouse gas emission levels. Accordingly, countries under the Convention realized the necessity of a much stronger initiative, which led the creation of the Kyoto Protocol.

1.2.2 Kyoto Protocol

As one of the major achievements of the Convention mentioned above, which entered into force in 1994, the Kyoto Protocol was adopted in order to legally bind[6] parties to limit or reduce their emissions of six greenhouse gases in 1997 (OECD (2005)). In February 16th 2005, the Kyoto Protocol, an international agreement to reduce GHG emissions of the world, was joined by more than 141 world countries. This was a great milestone, because in order to be effective, the Kyoto Protocol must be supported by more than 55 countries and also by countries that account for more than 55 percent of world CO_2 emissions. This target seemed impossible at first because the US, the largest emitter, had withdrawn from it in 2001. However, Russia's ratification of the Kyoto Protocol in 2004 made this target a reality.

This Protocol has set up emission targets for each country but there are differences in grades even though the overall target is reducing at least 5 percent of CO_2 emissions during 2008~2012, compared to the level of the year 1990. For example, during this period, the EU has to reduce 8 percent, the US 7 percent, Japan and Canada 6 percent respectively, and Australia has to reduce 8 percent of their CO_2 emission levels. There are additional targets in detail for other greenhouse gases and other mechanisms have been studied and implemented in order to secure flexibilities

[6] Legally binding reductions in greenhouse gas emissions of an average of 6 to 8% below 1990 levels between the years 2008-2012, defined as the first emissions budget period

for countries. Also, one important fact is that developing countries are exempted from these responsibilities for the first period of the Kyoto Protocol in order to give them more time to prepare for those responsibilities and also to give them more chances to industrialize their economies while developed countries have to sacrifice their economies to some extent. However, it is a fair decision in a sense that only 25 countries account for about 83 percent of global emissions while the remaining 140 countries contribute only 10 percent of annual emissions and those are normally least developed countries (UNFCCC (2006c)).

In addition to the emission target, the Kyoto Protocol provides three mechanisms to reach the target level efficiently. These three mechanisms are; International Emissions Trading, Joint Implementation, and the Clean Development Mechanism. The International Emissions Trading system allows industrialized countries to trade their emission amounts with developing countries in the international market, and Joint Implementation allows countries to jointly develop projects that can reduce the emission level. The Clean Development Mechanism serves to make developing countries develop clean technologies more efficiently by making industrialized countries aid developing countries financially in the production of such technologies (Barrett and Stavins (2003)).

1.3 Implications of International Cooperation

When the UNFCCC was created and the Kyoto Protocol was ratified, there was great hope and expectations that they would act as key drivers for reducing CO2 emissions curbing global climate change. A few years later, many people now question the effectiveness of those regimes in the respect that recent emission trends do not look positive. Even though there are downward trends, they are mainly due to economies in transition, not because of those greater emitters who should be responsible for the climate change. Rather, the emissions in most responsible countries have been increasing contrary to the expectation. One possible explanation is that those responsible countries increased their emission levels on purpose, considering that it would be much more beneficial if they emit as much as possible before the actual Kyoto implementation terms come into effect in order to boost their economies to the utmost. It could then be considered an example of the tragedy of commons. In addition, committed countries might not consider those regimes as binding thinking that they could withdraw whenever it is necessary, as shown in the US case.

It is still early to say that the Kyoto protocol has failed since the actual commitment period has not come yet. The data gathered from 1990-2006 implies that much stronger action is imperative since to date there has not been much improvement. Michael Porter argues that tougher standards trigger innovation and upgrading, according to his research (Porter (1991)). Also, the chief scientist at the World Bank, Robert Watson, said in the conference “Make markets work for climate” in Amsterdam, that spending needed to reduce heat-trapping emissions will cost less and offset bigger damage in the future. He also points out that an increase in temperatures by 2-3 degrees Celsius could lead to a loss of global economic growth by up to 3 percent and the costs of inaction could run between tens to hundreds of billions of dollars a year (Yereth (2006)). With the recognition of this fact, tougher standards for stronger actions could be introduced beyond the Kyoto Protocol.

1.4 Proposals to Kyoto Protocol

Throughout the decade, many scholars have suggested various ways to design international environmental conventions mechanisms more efficiently. Some scholars focused on developing green technology jointly. Benedick (2001) suggested that there should be technology development incentives to reach the Kyoto Protocol's target level. For creating the incentives he suggested there should be an international policy to aid the development of the clean technology such as carbon tax. Barrett (2003) suggested a similar idea in terms of developing green technology in a cooperative manner. In addition to this, he proposed to initiate R&D protocol so as to stimulate the development of the technology in a collaborative way. Some scholars focused on imposing international taxes on carbon. Cooper (2001) suggested that there should be a carbon tax to all participating countries within the regime. His proposal was somewhat different in that he did not differentiate developing and developed countries. He recommended that to reach a target level effectively domestic tax on the use of carbon should be the same throughout countries. Others were more attentive to increasing the participation in and deepening the commitment to environmental conventions. Victor (2001) suggested that we should allow countries to buy and sell unlimited emission allowances at an agreed price. He argued that it will render market oriented incentives to all participating countries and promote their commitment to the international regime more effectively. Lastly, some argued that we need to allocate more of the burden of reducing emissions to developing countries. Aldy, Orszag and Stiglitz (2001) and Stewart and Wiener (2001) suggested that developing countries should be more actively participating to reach the target level.

1.5 Purpose of the Thesis

Despite all these theoretical and empirical discussions, there have been no significant attempts to evaluate market outcomes that provide insights into the relationship between international competitiveness and global warming. Therefore, this paper introduces a theoretical framework where the strategic investment policy of each country can be examined in a model of international trade.

For many years, although scientists have been warning of these climate changes for some time, people have ignored climate change issues since they focused on the industrialization of their economies. Now, with the great concern on future life, international efforts in various sectors to curb the severe climate change have been made including the Kyoto Protocol. However, the difficulty associated with efficient provision of the global public goods has often been emphasized by many prominent scholars (Barrett (2003); Karp and Zhao (2008) among others)), and implementation mechanisms are suggested.

We however take a different approach to global climate change problems by investigating to what extent the commons of a clean environment is provided by the investment race of each country to maximize welfare through the development of green technology. This welfare consists of the weighted sum of profits from private firms which engage in international trade, and the utility from a country’s domestic environment. The model then offers a testable hypothesis on the determinants of the level of investment in clean technology and can be used to derive policy implications.

1.6 Organization of the Thesis

Chapter 2 presents the model that could be considered as a basic framework to examine the relationship between international trade and global warming. In the model two representative private firms compete in the global market and greenhouse gases are emitted from the production process. The government from each country intervenes to develop green technology which may reduce both production cost and emission of gases. The investment race between two countries is explained as a non-cooperative equilibrium and some testable propositions are derived from the comparative static analysis of equilibrium. Chapter 3 presents an empirical analysis of the determinants of investment in clean technology. It reports the result of empirical estimations of the importance of explanatory variables such as the degree of openness, unemployment rate and income level. Concluding comments are provided in Chapter 4.

Chapter 2

MODEL

2.1 Background

Although there has been a consensus among scholars on the significance of the climate change problem and the necessity of global efforts to curb global warming, the controversies over the way to solve the problem have continued. Even after the regime for climate change was ratified, many scholars from a number of different fields have still been proposing alternative options and asserting the need for redesigning the current regime.

Martin I.Hoffert *et al*. (2002) argued that the climate change problem is an energy problem, hence research and development on technology options to find an alternative way of using energy is necessary. Barrett (2006) also argued that it is imminent for us to invest in developing “breakthrough” technologies so as to curb global warming and guarantee sustainable development since the current Kyoto protocol approach does not provide any mechanisms that lead to the research and development of green technologies. He additionally argued that only the advanced technologies that have an increasing return to scale would perform better in the current anarchic international community.

In this section, we introduce a non-cooperative theoretical framework where we can examine a level of investment in clean technology for each country. We derive a series of empirically testable theoretical propositions.

2.2 Model Description

We examine a two-stage game theoretic model of the international competition among nations which consists of the competitive race of government investment in environment technology to clean the polluted air, and output competition in the final stage.

The model is based on the assumption that emissions of greenhouse gas (carbon dioxide) affect the welfare of neighboring country as air moves across the border between trading countries. For expositional convenience, we assume that there are two countries (1 and 2), and two representative firm 1 and 2 for each country, which compete in the world market for exports while producing at their home countries. The production of one unit of outputs necessitates the pollution of environment and increases co2 emission by k_i. If we denote the output of each firm by y_i, the remaining clean air for each country i can be expressed as $A_i = B_i - k_i y_i - k_j y_j$ for i, j = 1 and 2. B_i can be interpreted as utility derived from clean air measured in a monetary term. We also assume that the demand for the output in the world market is given by $P = a - by$ (where y= $y_1 + y_2$), and two firms compete in the quantity of the homogeneous output. We assume that the marginal production cost of each firm is given as $c_i(k_i)$ for $i = 1, 2$. Then the profit of each firm is then defined as

(2.1) $$\pi_i = \left[a - b(y_1 + y_2)\right] y_i - c_i(k_i) y_i \qquad \text{(where } i = 1, 2\text{)}$$

National welfare of each country is a function of profits and supply of clean air. Let us assume that social welfare is expressed as weighted average of profits and clean air, weight on profits being α_i for each country i. α_i is in general decided by political process within the country. The social welfare then is defined as follows in the open economy;

$$(2.2) \qquad W_i = \alpha_i \pi_i + (1-\alpha_i) A_i \qquad (i = 1, 2)$$

2.3 Theoretical Analysis of Model

Throughout the paper, we assume that the marginal production cost is constant once the co2 emission level is given. However, the private marginal cost born by each firm depends on k_i as the abatement cost depends on the pollution level. If the marginal abatement cost increases, we have $c_i(k_i) < 0$. However, if the green technologies to conserve energy and generate clean energy at an industrial level become cost effective to encourage their application, the cost function can have different property. For example, Barrett (2006) emphasized that the wide-spread use of breakthrough technology such as hydrogen-fuel motor would open the avenue for the green technology. ICT intensive technology which is devised to save energy may actually become a cleaner technology. In this sense, we can safely assume that $c_i'(k_i) > 0$ in the presence of green technologies.

2.3.1 Equilibrium in the Output market when Marginal Cost of Abatement is rising

We first examine equilibrium of our game when the marginal abatement cost is decreasing in ki. It used to be the case often quoted as the source of free-riding incentive. The profits of each firm is

(2.5) $$\Pi_1 = [a - b(y_1 + y_2) - c_1(k_1)]y_1$$

(2.6) $$\Pi_2 = [a - b(y_1 + y_2) - c_2(k_2)]y_2$$

It is straightforward to see that the Nash-Cournot equilibrium output can be expressed as follows:

(2.7) $$y_1(k_1, k_2) = \frac{a - 2c_1(k_1) + c_2(k_2)}{3b}$$

(2.8) $$y_2(k_1, k_2) = \frac{a + c_1(k_1) - 2c_2(k_2)}{3b}$$

Proposition 1

Assume that $\frac{\partial c_1(k_1)}{\partial k_1} < 0$ *and* $\frac{\partial c_2(k_2)}{\partial k_2} < 0$. *It then follows that* $\frac{\partial y_i(k_1, k_2)}{\partial k_i} > 0$ *and* $\frac{\partial y_j(k_1, k_2)}{\partial k_i} < 0$ *for* $i \neq j$ *and* $i, j = 1$ *and 2*

Proposition 1 shows that when the marginal cost of reducing CO2 increases in k_i, the output level of home (competitor) country increases (decreases) with k_i. It states that in the absence of welfare weight on clean environment, there exists no mechanism in the market to curb global warming.

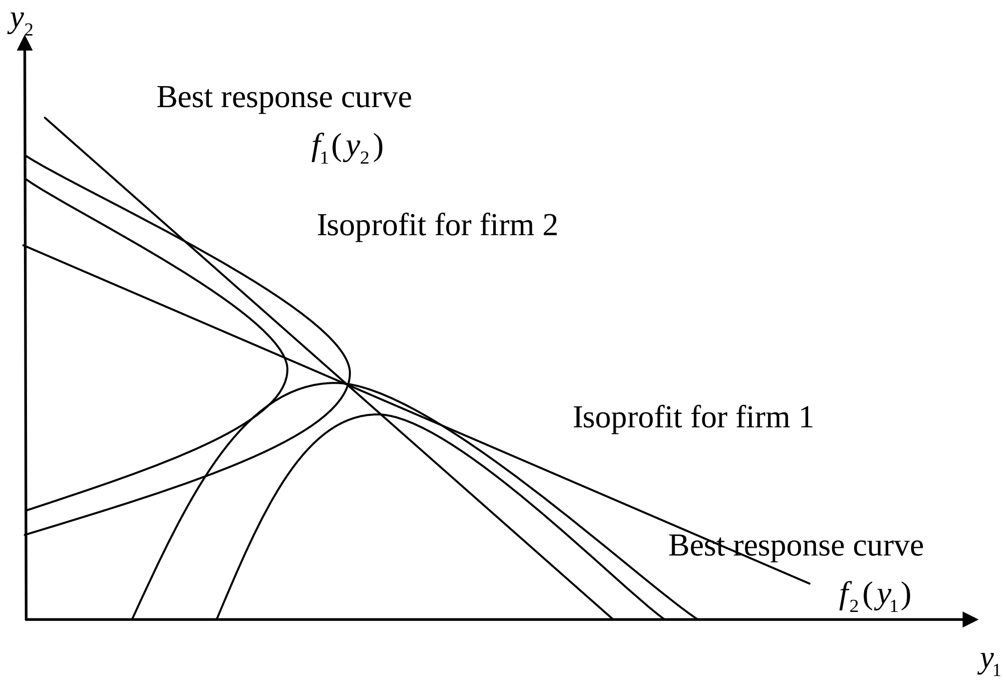

Figure 2.1 Best response curves and output determination

Figure 2.1 describes how the equilibrium output given emission cost $c_1(k_1)$ and $c_2(k_2)$.

When we assume $c_1'(k_1) < 0$ and $c_2'(k_2) < 0$, and when both firms decide to reduce CO2 emission best response curve for each firms shifts inward leading the decrease in the output production since the production cost increases. We note that as k_i increases, the marginal cost decreases and the best response curve shift outward to produce a new equilibrium where the market share of firm i is increased.

We now extend the model by incorporating the strategic determination of investment in reducing CO2 emission technology by each government. Given the welfare weights and level of technology, we can express welfare objective of each country by inserting equilibrium output levels from (7) and (8).

Let $W_i(y_i(k_i,k_j), y_j(k_i,k_j), k_i, \alpha_i)$ for i, j = 1, 2 denote such welfare levels.

Let $D_i = D_i(k_i(s_i))$ for i=1, 2 be cost associated with technology level, where $k_i(s_i) = \overline{k}_i - s_i$ for i=1 and 2. In addition, the technology development cost denoted as $D_i(s_i)$ is assumed to be an increasing convex function of s_i and the welfare for each country is assumed to be concave in s_i. That is, $\frac{\partial D_i}{\partial s_i} > 0$ and $\frac{\partial^2 D_i}{\partial s_i^{\ 2}} > 0$ for i=1, 2.

2.3.2 Non-Cooperative Equilibrium Level of Investment

Now consider a non-cooperative equilibrium level technology with the world optimum. Here we express world welfare as a function of s_1 and s_2. First, the welfare function for both countries can be written as follows:

(2.9) $$W_1(s_1,s_2) = \alpha_1\Pi_1(y_1(k_1(s_1),k_2(s_2)), y_2(k_1(s_1),k_2(s_2))$$
$$+(1-\alpha_1)(B_1 - k_1(s_1)y_1(k_1(s_1),k_2(s_2)) - k_2(s_2)y_2(k_1(s_1),k_2(s_2))$$
$$= \alpha_1\Pi_1(y_1(s_1,s_2), y_2(s_1,s_2)) + (1-\alpha_1)(B_1 + s_1y_1(s_1,s_2) + s_2y_2(s_1,s_2))$$

(2.10) $$W_2(s_1,s_2) = \alpha_2\Pi_2(y_1(k_1,k_2), y_2(k_1,k_2)) + (1-\alpha_2)(B_2 - k_1y_1(k_1,k_2) - k_2y_2(k_1,k_2))$$
$$= \alpha_2\Pi_2(y_1(s_1,s_2), y_2(s_1,s_2)) + (1-\alpha_2)(B_2 + s_1y_1(s_1,s_2) + s_2y_2(s_1,s_2))$$

We first consider non-cooperative determination of technology level of each country. Each country decides its best response by maximizing welfare net of costs associated with technology level. In fact, given k_1 and k_2, country 1 and 2 determine best response from the following equations:

(2.11) $$\frac{d(W_1 - D_1(s_1))}{ds_1} =$$

$$\frac{\partial W_1(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial y_1(s_1,s_2)}\frac{\partial y_1(s_1,s_2)}{\partial s_1}+\frac{\partial W_1(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial y_2}\frac{\partial y_2(s_1,s_2)}{\partial s_1}$$

$$+\frac{\partial W_1(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial s_1}-D'(s_1)=0$$

(2.12) $$\frac{d(W_2-D_2(s_2))}{ds_2}=$$

$$\frac{\partial W_2(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial y_1(s_1,s_2)}\frac{\partial y_2(s_1,s_2)}{\partial s_1}+\frac{\partial W_2(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial y_2}\frac{\partial y_2(s_1,s_2)}{\partial s_2}$$

$$+\frac{\partial W_2(y_1(s_1,s_2),y_2(s_1,s_2))}{\partial s_2}-D'(s_2)=0$$

By solving the best response curve for each country we can derive the equilibrium technology levels for each country 1 and 2. Let us denote the non-cooperative equilibrium technology level as $\hat{s}_1$ and $\hat{s}_2$. We examine comparative static results of this equilibrium in the later in this chapter.

2.3.3 Inefficiency of Non-Cooperative Equilibrium

Now we consider the world optimum technology level. World welfare function is defined as the sum of two domestic welfare functions. Let us denote it as $W^*(s_1,s_2;\alpha_1,\alpha_2)$. Therefore,

(2.13)

$$W^*(s_1,s_2;\alpha_1,\alpha_2)=\alpha_1\Pi_1(y_1(s_1,s_2),y_2(s_1,s_2))+(1-\alpha_1)(B_1+s_1y_1(s_1,s_2)+s_2y_2(s_1,s_2))$$

$$+\alpha_2\Pi_2(y_1(s_1,s_2),y_2(s_1,s_2))+(1-\alpha_2)(B_2+s_1y_1(s_1,s_2)+s_2y_2(s_1,s_2))$$

Here again we consider technology development cost for the world. Therefore the welfare net of technology development cost can be written as

$$W^*(y_1(s_1,s_2), y_2(s_1,s_2)) - D_1(s_1) - D_2(s_2)$$

If we assume that there is an international authority to govern the world, the world optimum technology level for both countries would be selected so as to maximize the world welfare. Thus, the world optimum technology level can be derived by simply taking the first order condition of the world welfare function with respect to s_1 and s_2. Let us denote the world optimum level of reduction in CO2 as s_1^* and s_2^*. Recall that welfare function for each country is concave in s_i $(i=1,2)$ and the world level of technology is decided by solving the equations below:

(2.14) $$\frac{\partial W_1}{\partial s_1} + \frac{\partial W_2}{\partial s_1} - D_1' = 0$$

(2.15) $$\frac{\partial W_1}{\partial s_2} + \frac{\partial W_2}{\partial s_2} - D_2' = 0$$

A natural question to ask is whether there exists any divergence between the world optimum level of investment and non-cooperative equilibrium level. This question can be examined by simply comparing the level of the world's optimum technology with the Nash equilibrium level. Before beginning our analysis, let us assume that country 2 decided to take the offer from the World Authority, say World Bank or UN so that their technology level is fixed to s_2^*.

Then we have

(2.16) $$\frac{\partial(W_1 - D_1)}{\partial s_1} = -\frac{\partial W_2}{\partial s_1} \text{ where } W_2 = W_2(y_1, y_2, s_1, s_2)$$

We also know from simple chain rule that,

(2.17) $$\frac{\partial W_2}{\partial s_1} = \frac{\partial W_2}{\partial y_1}\frac{\partial y_1}{\partial s_1} + \frac{\partial W_2}{\partial y_2}\frac{\partial y_2}{\partial s_1}$$

where y_1 and y_2 is selected through second stage Cournot competitions that described earlier.

Therefore,

(2.18) $$\frac{\partial W_2}{\partial s_1} = \alpha\left\{\frac{\partial \Pi_2}{\partial y_1}\frac{\partial y_1}{\partial s_1} + \frac{\partial \Pi_2}{\partial y_2}\frac{\partial y_2}{\partial s_1}\right\} + (1-\alpha)\left\{-y_1(s_{1,}s_2)\frac{\partial k_1}{\partial s_1} - k_1\frac{\partial y_1}{\partial s_1} - k_2\frac{\partial y_2}{\partial s_1}\right\}$$

The first term expresses the effect of increased efficiency of country 1 on the profits of country 2. The second term denotes the resulting welfare effects of country 2 when the country 1 reduces emission of greenhouse gas.

Since $\left(\frac{\partial \Pi_2}{\partial y_1}\frac{\partial y_1}{\partial s_1}\right) > 0$, $\left(-y_1(s_{1,}s_2)\frac{\partial k_1}{\partial s_1}\right) > 0$, $\left(-k_2\frac{\partial y_2}{\partial s_1}\right) < 0$ and $\left(-k_1\frac{\partial y_1}{\partial s_1}\right) > 0$ the sign of $\frac{\partial W_2}{\partial s_1}$ is not obvious. Therefore it is not apparent whether non-cooperative technology level falls short of the world level.

However, there are certain cases where the sign of $\frac{\partial W_2}{\partial s_1}$ is unambiguous. Let us consider the symmetric case for both countries 1 and 2. That is, initial level of "dirty" air for both countries and tax cost for both firm in country 1 and 2 are exactly the same. We can write the condition as follows:

.

(2.19) $\bar{k}_1 = \bar{k}_2$

(2.20) $c_1(\cdot) = c_2(\cdot)$

Recall the Cournot output equilibrium, the equation (7) and (8)

$$y_1(k_1,k_2) = \frac{a - 2c_1(k_1) + c_2(k_2)}{3b}$$

$$.y_2(k_1,k_2) = \frac{a + c_1(k_1) - 2c_2(k_2)}{3b}$$

Therefore,

(2.21) $$\frac{\partial W_2(s_1, s_2)}{\partial s_1}$$

$$= -\frac{2\alpha_1}{3}\frac{\partial c_1(k_1)}{\partial k_1} y_2(k_{1,}k_2) + (1-\alpha_1)\left\{ -y_1(k_{1,}k_2)\frac{\partial k_1}{\partial s_1} + k_1\left[\frac{2}{3b}\frac{\partial c_1(s_1)}{\partial s_1}\right] + k_2\left[\frac{1}{3b}\frac{\partial c_1(s_1)}{\partial s_1}\right]\right\}$$

$$= \frac{2\alpha_1}{3}\left(\frac{a_1 + c_1(s_1) - 2c_2(s_2)}{3b}\right) + (1-\alpha_1)\left(y_1(k_{1,}k_2) + \frac{2k_1 + k_2}{3b}\right)\frac{\partial c_1(s_1)}{\partial s_1}$$

$$= \frac{2}{3}\alpha_1\left(\frac{a-c}{3b}\right) + (1-\alpha_1)\left(\frac{a-c}{3b} + \frac{1}{b}k_1\frac{\partial c_1(s_1)}{\partial s_1}\right)$$

For $\frac{\partial W_2}{\partial s_1}$ to be positive we need a condition $\frac{a-c}{3b} + \frac{k_1}{3b}\frac{\partial c_1(s_1)}{\partial s_1} > 0$ and $\left(\frac{a-c}{3b}\right)$. Since we assumed that $\frac{\partial c_1(s_1)}{\partial s_1} > 0$, and we know from our demand function that the intercept is a so that it should be larger than c, the comparison between $\hat{s}_1$ and s_1^* is as follows:

If $\frac{\partial c_1(s_1)}{\partial s_1} > 0 > \frac{c-a}{3k_1}$ and this implies that $\frac{\partial(W_1 - D_1)}{\partial s_1} < 0$ so that $\hat{s}_1 < s_1^*$.

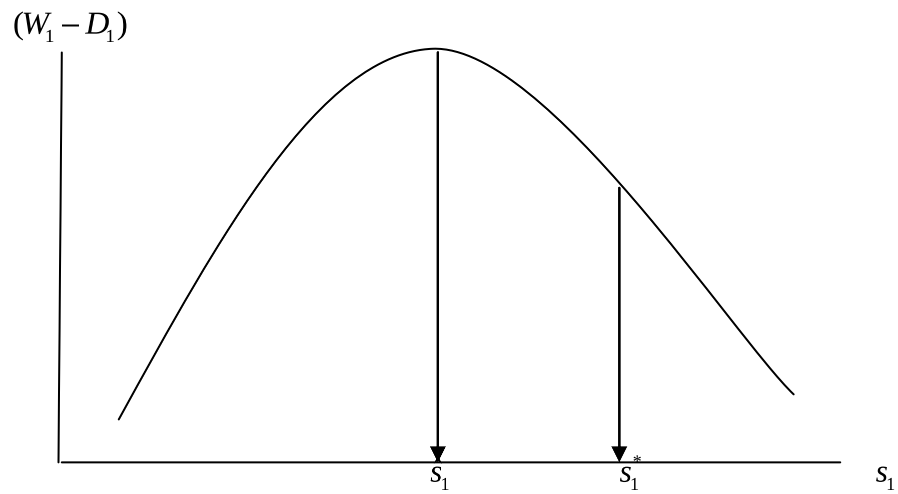

Figure 2.2 Comparison between World optimal and Nash Equilibrium Technology Level, where $c_i'(k_i) < 0$

Proposition 2

Suppose $c_i'(k_i) < 0$, $D_i'(s_i) > 0$ *and* $D_i''(s_i) > 0$ *for* $i = 1, 2$*, then in the symmetric case where two countries faces the same technology and environment under the same welfare weights, non-cooperative equilibrium level of investment in technological development falls short of world optimum level.*

2.3.4 Green Technology Reconsidered

Consider now the case that the production method, which pollutes less amount of environment, is more efficient in the sense that it uses less energy. We can think of ICT (Intensive Production Technology), which economizes on energy, material and time etc. Then, our assumption on $c_i'(k_i)$ changes in the opposite direction so that $c_i'(k_i) > 0$. Then the proposition 1 changes accordingly so that the country which uses greener technology gains the competitive advantage. In other words, $\frac{\partial y_i}{\partial k_j} < 0$ for

$i = j$ and $\frac{\partial y_i}{\partial k_j} > 0$ for $i \neq j$. Nevertheless, the sign of equation (18) however becomes indeterminate again. However, we can again consider the perfectly symmetric case for both countries 1 and 2. That is, if equality (19) and (20) holds, for $\frac{\partial W_2}{\partial s_1}$ to be positive we need a condition $\frac{a-c}{3b} + \frac{k_1}{b}\frac{\partial c_1(s_1)}{\partial s_1} > 0$.

That is, it must hold $\frac{\partial c_1(s_1)}{\partial s_1} > \frac{c-a}{3k_1}$.

For $\frac{\partial W_2}{\partial s_1}$ to be negative, however, opposite inequality must hold. As mentioned, we know from our demand function that the intercept is a so that it should be larger than c.

Therefore the comparison between $\hat{s}_1$ and s_1^* depends on two different cases.

Case1. $\frac{c-a}{3k_1} < \frac{\partial c_1(s_1)}{\partial s_1} < 0$, which implies that $\frac{\partial (W_1 - D_1)}{\partial s_1} < 0$ so that $\hat{s}_1 < s_1^*$

Case2. $\frac{\partial c_1(s_1)}{\partial s_1} < \frac{c-a}{3k_1} < 0$, which implies that $\frac{\partial (W_1 - D_1)}{\partial s_1} > 0$ so that $\hat{s}_1 > s_1^*$

To illustrate our point graphically, we can draw a concave function for $(W_1 - D_1)$ with respect to s_1 given s_2^*.

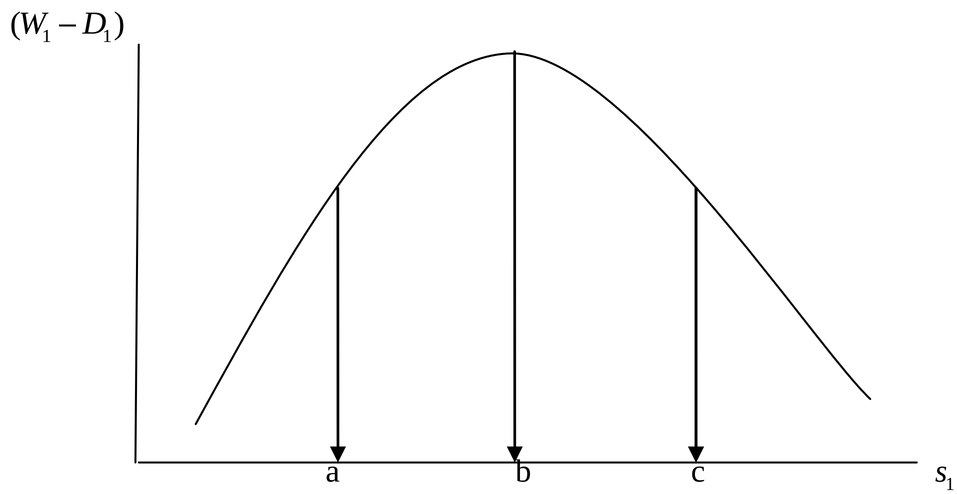

Figure 2.3 Comparison between World optimal and Nash Equilibrium Technology Level, where $c_i'(k_i) > 0$

From Figure 2.2, we know that point "b" is non-cooperative technology level and point "a" and "c" are candidates for world optimum technology level for country 1 given country 2's world optimum technology level s_2^*.

Thus, in the perfectly symmetric case where equation (19) and (20) hold, we know that the world optimum technology level is different from non-cooperative equilibrium technology level and the difference depends on the relative magnitude of $\frac{c-a}{3k_1}$ and $\frac{\partial c_1(s_1)}{\partial s_1}$.

Now let us consider the elasticity of cost with respect to CO2 emission. The elasticity is written as $\varepsilon = \frac{d \ln c_1(k_1)}{d \ln k_1}$. From the definition of the elasticity we know the following:

(2.22) $$c_1'(k_1)k_1 = \varepsilon c(k_1)$$

Therefore, over and under investment of the technology depends on the following inequalities.

Case 1. $c(k_1) > \frac{a}{3\varepsilon+1}$

Case 2. $c(k_1) < \frac{a}{3\varepsilon+1}$

In case 1, non-cooperative determination results in over investment on technology level than the world optimum level and, in case 2, under-investment. We state this result in the following proposition.

Proposition 3

Suppose $c_i\,'(k_i) > 0$ *for* $i = 1, 2$. *Then in the symmetric case where two countries faces the same technology and environment under the same welfare weights, the world optimum technology level and non-cooperative equilibrium for technology level depends on elasticity of the cost with respect to k. Depending on the inequality* $c(k_1) > \frac{a}{3\varepsilon+1}$ *or* $c(k_1) < \frac{a}{3\varepsilon+1}$, *overinvestment or underinvestment can prevail.*

Consider the case when $c_1(k_1) = t_1 k_1$ where t>0. The elasticity then equals to 1. If we apply proposition 2, then under-investment prevails depending on $c_1(k_1) < \frac{a}{4}$.

The intuition behind the proposition 3 is that when the avenue of green technology is open and available, it is likely that the government have to invest more aggressively to gain the international competitiveness. It is also sustainable politically since it upgrades the domestic environment as well. In the certain case that we examined in the Proposition 3, this incentive may be greater that the incentive for free riding.

The proposition 2 and 3 are valid only when two countries are in the symmetric situation. If the difference between the two countries is large enough, the model may need to be changed to reflect asymmetric positions as in the model of leader-follower in the oligopoly market. However, we do not pursue this topic in our thesis.

We now attempt to derive some theoretical propositions that have policy implication. Although the comparative static analysis of the Nash equilibrium level of investment with respect to exogenous variables such as degree of openness, welfare weights and the cost of development is complicated, we here attempt to sketch the underlying reasoning and use it to derive some testable hypothesis in the next chapter. These propositions will be tested in the next chapter.

2.3.5 The Effect of a Change in Degree of Openness

Degree of openness is an important determinant of technological investment. Suppose $c_i'(k_i) > 0$ as in the proposition 3. We compare the marginal effect of a change in k_i on domestic profits and utility from clean environment before and after the economy opens. When there is no trade between the two countries, the effect of greener technology for country 1 is confined to an increase in domestic monopoly profits and changes in harmful effect on environment, which is captured as $\frac{d\left[k_1 y_1(k_1)\right]}{dk_1}$.

However, when the economy opens, the effect of greener technology on the profits of domestic firm is realized through an increase of the market share of the domestic firm in the international duopoly market. Since the perceived marginal revenue in the world duopoly market is greater than the marginal revenue of monopoly firm in the closed domestic market, the profit effect becomes greater than in the closed economy. We sketch the underlying reasoning in a simple model with two symmetric countries.

We first explain that the perceived marginal revenue for the duopoly firm in the open economy has a lower slope than the slope of autarky. Although this does not hold generally, it is true in the symmetric case where the intercept of demand function and output levels are the same for both firms. Suppose that the firm in the closed economy faces the demand function $p = a_i - by_i$. Then the world demand function for firms that operate at an open duopoly economy becomes $p = a - \frac{b}{2}y$ for symmetric case where $a_1 = a_2$ and $y_1 = y_2$. The marginal revenue for domestic monopoly is $a - 2by$ so that the monopoly output becomes $\frac{(a-c)}{2b}$ for any cost level c. On the other hand, the perceived marginal revenue for firm i in an open economy becomes

(2.23) $$\frac{d\left(a - \frac{b}{2}(y_1 + y_2)\right)y_1}{dy_1} = a - by_1 - \frac{b}{2}y_2 = a - b\frac{y}{2} - \frac{b}{4}y = a - \frac{3b}{4}y$$

where y denotes world output and each firm produces half of it. The resulting output for the duopoly firm is derived from the half of the world output, $a - \frac{3b}{4}y = c$, namely $y = \frac{4(a-c)}{3b}$.

Therefore the output of a duopoly firm becomes $y = \frac{4(a-c)}{6b}$, which is greater than the domestic monopoly output in the autarky.

Suppose now that $c_i'(k_i) > 0$ and symmetric firms exist facing the same market demand as we stated above. Figure 2.4 shows the benefit of trade for firms when their perceived marginal revenue moves outward as the economy opens. When the marginal cost for production at country 1 decreases from $c_1(k_1)$ to $c_1(k_1')$, the resulting increase in profit changes from [abde] to [acdf] as the economy opens.

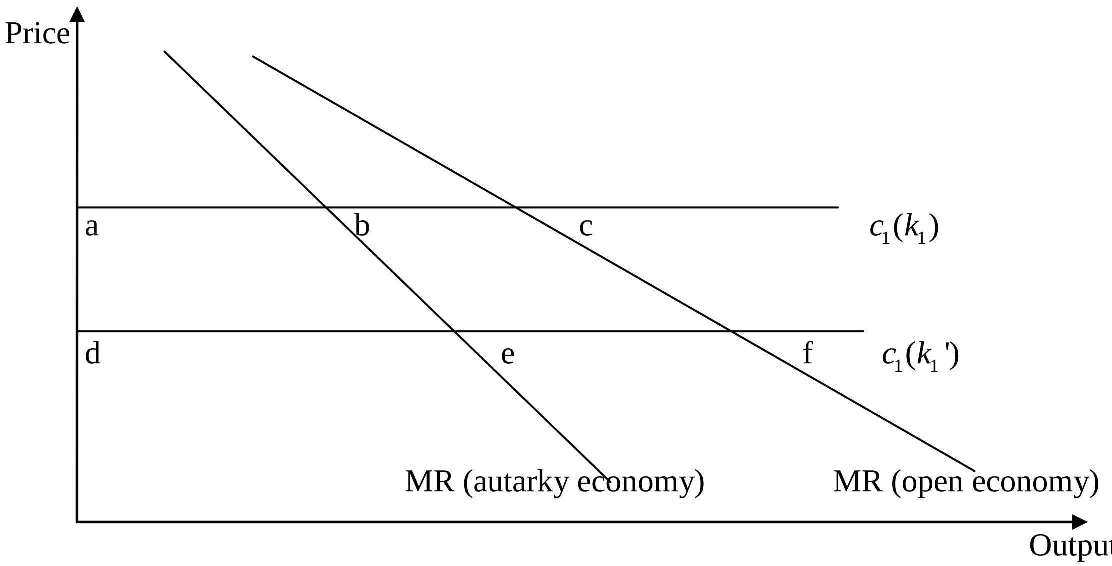

Figure 2.4 Increase in profits when k_1 changes from k_1 to k_1'

Furthermore since the output of the competitive foreign firm decreases, it reduces the harmful external effect of the foreign firm ($k_2 \frac{d\left[y_2(k_2)\right]}{dk_2}$).

Since the changes in marginal harmful effects of an increase in domestic output($k_1 \frac{d\left[y_1(k_1)\right]}{dk_1}$) remains the same as in the autarky economy, we can conclude that when the economy opens, the marginal effect of an investment in green technology on social welfare becomes greater than in the autarky economy. We summarize this as the following graph and proposition

Proposition 4

Suppose the assumption on $c_i'(k_i)$ holds as in Proposition 3 and suppose both representative firms for each country is symmetric. As the economy liberalize the trade, the technological investment level becomes greater than in the closed autarky economy.

2.3.6 The Effect of a Change in Development Cost

Consider now the case when the cost of development of green technology decreases. The effect on the Nash equilibrium is very complicated. Suppose, however, that the welfare weight on environment is zero so that national policy target consists solely of profit. At the Cournot equilibrium in the output market, the profits of home firm becomes

(2.24) $$\prod_1 = \frac{\left[a - 2c_1(k_1) + c_2(k_2)\right]^2}{9b}$$

Then the same holds for foreign firm 2. We can easily calculate the effect of cost changes on the Nash equilibrium level of k_i. Under the same assumption as in the proposition 3, we have

(2.25) $$\frac{\partial \prod_1}{\partial s_1} = \frac{-4(a - 2c_1(k_1) + c_2(k_2))}{9b} \frac{dc_1}{dk_1} \frac{dk_1}{ds_1}$$

$$= \frac{4}{9b} \frac{dc_1}{dk_1} (a - 2c_1(k_1) + c_2(k_2)) = \frac{(a - 2c_1(k_1) + c_2(k_2))}{3b} \frac{4}{3} \frac{dc_1}{dk_1}$$

$$= y_1 \frac{4}{3} \frac{dc_1}{dk_1}$$

Let us write the first-order condition as $\frac{\partial \prod_1}{\partial s_1} = D'(s_1) = d_1$. In order to figure out the shape of best response function for both countries we need to take a look at second partial derivative with respect to both s_1 and s_2. These are given by:

(2.26) $$\frac{\partial^2 \prod_1}{\partial s_1^2} = \frac{\partial y_1}{\partial s_1} \frac{4}{3} \frac{d^2 c_1}{dk_1^2} \frac{dk_1}{ds_1} = -\frac{\partial y_1}{\partial s_1} \frac{4}{3} \frac{d^2 c_1}{dk_1^2}$$

(2.27) $$\frac{\partial^2 \prod_1}{\partial s_1 \partial s_2} = \frac{\partial}{\partial s_2}\left[\frac{a - 2c_1(k_1) + c_2(k_2)}{3b} \frac{4}{3} \frac{dc_1}{dk_1}\right] = \frac{1}{3b} \frac{4}{3} \frac{dc_2}{dk_2} \frac{dk_2}{ds_2} = -\frac{1}{3b} \frac{4}{3} \frac{dc_2}{dk_2}$$

Second partial derivative of profits with respect to s_1 becomes negative if we assume that $\frac{d^2 c_1}{dk_1^2} > 0$ since $\frac{\partial y_1}{\partial s_1} > 0$ and cross partial derivative with respect to s_2 becomes negative if we assume that $\frac{dc_2}{dk_2} > 0$ given the assumption that $c_1'(k_1) > 0$. Therefore we can conclude that s_1 and s_2 are strategic substitutes ($\frac{ds_1}{ds_2} < 0$) and that as d_1 decreases, given s_2, the best response curve of country 1 moves to rightward direction. Since we know that $\frac{d \prod_1}{ds_1} > 0$, $\frac{\partial^2 \prod_1}{\partial s_1^2} < 0$ and $\frac{\partial^2 \prod_1}{\partial s_1 \partial s_2} < 0$ we can plot the relationship between s_1 and s_2 as in Fig 2.4.

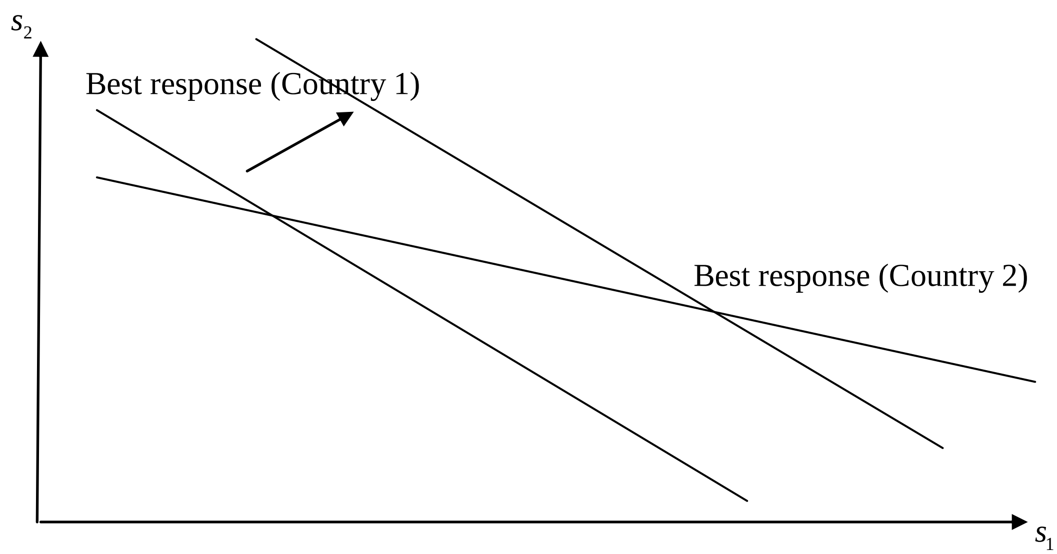

Figure 2.5 Strategic Substitutes s_1 and s_2

In this case, the investment level at Nash equilibrium increases when the cost of development decreases. Although we derived the result assuming that the welfare weight for the environment is zero, it holds in general when the welfare for profits is sufficiently great. We state this as the following proposition.

Proposition 5

Under the maintained assumption on the cost $c_i'(k_i) > 0$ *as in the proposition 3, the investment level increase when the cost of development decreases if the welfare weight for profits is sufficiently close to 1.*

2.3.7 The Effect of a Change in Welfare Weight

In addition to this, we now consider our last testable assumption. Although it would be interesting to see the effect of welfare weight on both growth and environment on Nash equilibrium it is quite difficult to derive obvious comparative statics results because of the complication of equilibrium levels. Here however we assume stricter assumption in order to draw some implication of welfare weight effect on Nash equilibrium level. Let us assume the following:

(2.28) $$c_1(k_1) = c_2(k_2) = 0$$

Then equilibrium output and profit levels for both firms no longer depend on k_i values. Thus, the first order condition for welfare maximization for country 1 would be as follows:

(2.29) $$\frac{\partial W_i}{\partial s_i} = (1-\alpha_i)y_1 - D'(s_i) \qquad \text{where } i = 1, 2$$

When c_1 and c_2 are not affected by k_1 and k_2 the optimal s_i^* increases as marginal development cost $D_i'(s_i) > 0$ decreases. Therefore given $D_i'(s_i) > 0$ and $D_i''(s_i) > 0$ when α_i increase the optimum s_i^* decreases.

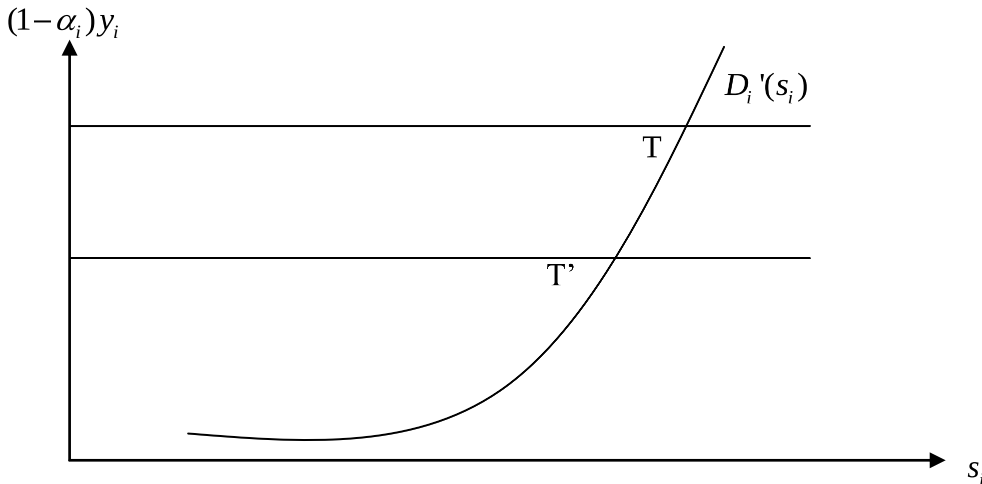

Figure 2.6 Welfare Weight and Equilibrium Technology Level

From Figure 2.6, we can see the effect of welfare weight for output expansion on equilibrium technology level. As the welfare weight α_i increases, the equilibrium point moves from T to T’. And this implies decreasing clean technology investment. Thus, we can summarize the effect of welfare weight into following proposition.

Proposition 6

Suppose that c_i *is not affected by* k_i *for* $i = 1, 2$. *The optimal* s_i^* *increases (decreases) as marginal development cost* $D_i'(s_i) > 0$ *decreases (increases) and* *technology investment increases (decreases) where* $i = 1, 2$.

2.4 Policy Implication

The policy implications from our analysis are not straightforward. In the absence of coordinated efforts, each country has differential incentives for investment in clean technology. Those countries with certain favorable characteristics with high degree of openness, low development cost and greater revealed preference for clean environment may lead the investment. As we stated earlier in Chapter 1, there may arise a need for international assistance from developed leading countries to lagging developing countries in coping with technological challenges to curb global warming.

The paper has shown also that a non-cooperative equilibrium level of investment is different from the world optimum level of investment and there have to be coordinated efforts to achieve an efficient level. It would however be extremely difficult to design an incentive compatible mechanism that can allocate the cost burden of developing a world optimum technology. The theoretical propositions suggest that in certain cases where the reduction of greenhouse gases also decreases production costs, each government have enough incentive to invest in such technology. When so called green technologies are available, it is likely that the government invest more aggressively to gain the international competitiveness. It is also sustainable politically since it upgrades the domestic environment as well. This effect certainly has to be considered in the design of incentive compatible mechanism for developing 'break-through' technologies (Barrett, 2006).

It would also be interesting if we can examine the government tax policy that influence the private cost of greenhouse emission and international competitiveness.

The credible change in tax policy certainly influences the entrepreneurial activities in international output market and subsequently the final investment policy. However, unless we specify how the tax revenue is spent for social welfare, it would be extremely complicated to examine the tax policy in our model.

2.5 Issues remained open for discussion

There are a few shortcomings of our analysis which we would like to emphasize before we move on to the next chapter. First, in our theoretical model, we mainly assumed that two countries are in a strategically symmetric position. However, in the real world, the technological bases for developing green technologies are not symmetric. It will be an interesting area for future research to model the asymmetric case. Second, we assumed away the existence of non-tradable sector which is insulated from international competition. The basic intuition is that if the non-tradable sector is small enough, our proposition will remain intact. Incorporation of non-tradable sector makes our model more complicated to derive theoretical propositions unless we impose more restrictive assumptions. We, however, leave this topic also for the future research area. Third, there can be privately sponsored research and development efforts for green technologies which we largely neglected. We implicitly assumed that the private R&D result is already reflected in the private production cost of production. However, the role of private R&D and public R&D need to be further clarified in the future work.

Chapter 3

EMPIRICAL MODEL AND ANALYSIS

3.1 Motivation

In this chapter, we bring the model to the data, and examine if the findings from the theoretical model in chapter 2 are supported empirically. Our dataset contains over 200 countries that have different political, economic and cultural aspects. These would allow us to take a closer look at the characteristics and incentives of countries, and to learn which of these countries favor or disfavor the technology investment option. In order to estimate the determinants that reflect these characteristics and incentives, we first review the existing literature on the relationship between environment and socio-economic variables.

3.2 Literature Review

As discussed in the previous chapter, we will conduct empirical analysis using our panel data set to find socio-economic variables that affect the technology level and emission of greenhouse gas.

Over the past decades, there have been a growing number of studies, which attempt to figure out the socio-economic determinants of environmental pollution. Since the purpose of our empirical analysis is to estimate the impact of socio economic variables that might affect the national clean technology level, a review of the literature on this research topic provides some insights as to our choice of variables.

Grossman and Krueger (1995) find that income and lagged income variables play an important role in determining levels of air and water pollution. Similar to this study, Selden and Song (1994) try to examine whether a non-linear relationship between pollution level and income status exists, and they name this non -linear relationship an Environmental Kuznet Curve (EKC).

However, a study by Congleton (1992) deploys political variables to explain his dependent pollution proxy variables, such as Methane and Chlorofluorocarbon. These variables he uses include both capitalist and democratic countries, the amount of conserved energy, population, and GNP. In this study he finds that democracy variables are quite effective in explaining the level of pollution.

Torras and Boyce (1998) meanwhile select geographical regional variables and a proxy for urbanization and find that some positive effects from those variables on pollution exist. They also use the degree of political liberty, degree of inequality, and literacy rate for both high and low income countries to differentiate the effect of their independent variables on pollution. However, the results of their empirical analysis are not enough to prove that those political variables are responsible for pollution since the political variables they choose are not statistically significant.

Neumayer (2003) uses other political variables, such as the share of left seats, green seats, and the share of both left and green seats in each country’s legislature. However, no strong relation existed between any of these political variables and pollution variables. Grassebner, Lamla and Strum (2006) also examine similar political variables, such as political freedom, duration of executives in office, and left wing power. Although none of them prove to be effective independent variables, Grassebner, Lamla and Strum discovered that dictatorship was partially responsible for the amount of CO_2 emission.

In addition to these studies on political variables, many others such as Cole

(2004), McAusland (2003), Mani and Wheeler (1998) and Grassebner, Lamla and Sturm (2006) use independent variables that can serve as a proxy for the degree of openness to find out the relationship between pollution and trade. Some of them argue that trade has negative effects on environment and others argue the opposite. For instance, Cole (2004) finds that as countries open their economy more, it appears that they are more likely to adopt cleaner technology, leading such countries to use more efficient methods to reduce carbon emissions. However, Mani and Wheeler (1998) present the opposite finding about the same issue. They argue that trade outsources the environmentally friendly industries to low income countries making the pollution level of low income countries higher as they become more open. Grassebner, Lamla and Strum (2006) argue that the effect of international trade should be divided into three categories, a method which Grossman and Krueger (1995) employ in order to examine the relationship between growth and the environment. These categories are referred to as the composition effect, scale effect and technology effect. Grassebner, Lamla and Strum (2006) claim that because of the different kinds of economies of scale and the difficulty of obtaining micro industry data to judge which industry has a comparative advantage, it would be difficult to find the overall effect of this trade. They use two different proxies for trade; the inward foreign direct investment (FDI) as a percentage of GDP and the traditional degree of openness measure, that is, the ratio of import plus export volume divided by GDP. Although they could not find any effect of FDI, they prove that there exists a positive relation between their degree of openness and air pollution.

In the next section we present a different set of testable hypotheses on global warming. Although the sample size, years of observation and the dependent variable are different from the above literature, we consider independent variables similar to those that have already been used. We, however, also examine the relevance of socio-economic variables in great detail.

3.3 Empirical Model Description

3.3.1 Testable Hypotheses

As mentioned, our rationale for the empirical analysis is to test the validity of the theoretical proposition that we derive in Chapter 2. Recall, in chapter 2 we develop a non-cooperative equilibrium model to determine the optimum level of green technology investment and overall output production and derive some propositions on the inefficiency of this equilibrium investment level. Unfortunately it is beyond the scope of this thesis to estimate the extent to which this firm level investment and production differs from the world optimum. However, we present a series of ensuing propositions, which are within the grasp of our current study, in order to identify a certain set of country characteristics which provide investment incentives for clean technology. Let us again review the arguments of these testable propositions.

We notice that countries can exert more efforts on R&D for green technology because there is an incentive not to be dominated in international output competition. This is in contrast with the traditional free riding incentive for the use of the commons, namely fresh air. In addition, we find that countries tend to invest more in green technology as they open their trade in order to achieve a greater level of domestic welfare. Furthermore, we also find that if the welfare weight for profit is sufficiently close to 1, investment in green technology increases as the technology development cost decreases.[7] However, if the welfare weight on profit is zero, countries have an incentive to free ride and rely on their neighbors to reduce carbon emissions, regardless of the technology development costs.

Given these testable hypotheses, there are a number of considerations we must address before beginning our empirical analysis. The tests for these propositions require strict assumptions, just like those of which we made use in our theoretical model testing. Real data, however, cannot adopt these assumptions and collecting all the micro data on marginal costs from the entire industry is not feasible in reality. Therefore, we do not attempt to estimate the exact welfare weights and technology development costs used in our theoretical model. Rather than estimate these parameters directly, we attempt to use socio-economic explanatory variables that we think contain information on the welfare weights for profits and clean environment or provide us with an indication of technology development costs.

Hence, our empirical analysis aims to examine what characteristics of a country are favorable to investment in technology that reduces greenhouse gas. Before we introduce an econometric model, we summarize the testable propositions as follows.

Testable Hypothesis 1: Degree of openness affects investment favorably.

To examine this hypothesis, we use two openness measures. The first openness measure is the sum of total import and export amounts divided by GDP. The second is the Sachs and Warner openness measure. By using these measures, we check whether an increase in degree of openness leads to an increase in environmental

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[7] Recall that the welfare weights on profit and clean air are numerical values that, through their inclusion in our optimization problem, represent the importance our society places on each item.

technology investment, which is consistent with the result derived in our theoretical model. Recall from our model, a high degree of trade openness implies an inflow of foreign advanced technology that should reduce development cost, and is associated with increasing cultural interactions and a shared value system which may lead to a high desire for green technology.

Testable Hypothesis 2: As the development cost of green technology decreases, investment in green technology increases.

We examine which proxy variables affect the development cost on environmental technology. First, the accumulated scientific knowledge and engineering know-how of the country certainly affects the cost of development. We presume that this technological base is positively associated with the level of per capital income Second, as stated in the previous hypothesis, degree of openness affects the cost of developing green technology since the trade liberalization could make it easier to access the clean technology lowering the development cost of reducing greenhouse emission (Cole (2004)).

We also consider degree of democracy (DEMO) as a proxy. High degree of democracy exerts influence on the environmental technology development cost and this influence can be both positive and negative in decreasing the cost. This is because costs incur in countries with high degree of democracy as a way of encompassing the opinion of minorities and this cost on green technology development differs depending on the preference of minorities in one country. Since we do not have prior information on the political preference of minorities, we gauge the relationship between DEMO and environmental technology development cost by using three country dummies divided by different income levels.

Testable Hypothesis 3: If green technology has negligible effect on the private cost of production, an increase in welfare weight on profit decreases the investment in green technology.

To test the above hypothesis, we need to find some surrogate variable to proxy our welfare weight on profit. For this proxy we use unemployment rate, income level, and degree of democracy, allowing for regional variation with regional dummy variables.

The well known presumption is that as income grows, society has a tendency to place more emphasis on environmental protection. We categorize countries in accordance with different income levels to see whether any difference exists in the level of green technology investment among different income groups. We use three different income groups based on data defined by the United Nations for approximately 200 sample countries in this test. These groups consist of high income countries for the top 36 countries with high income level (HIGH), BRICs countries for the fastest-growing four countries (BRICs) - Brazil, Russia, India and China, and non-high income countries for the rest of sample (NONHIGH). The rationale for this grouping based on income levels is as follows; as a country improves its income level, its environmental concerns grow, followed by national pressure for policy reform that discourages the use of pollution causing technologies. This policy reform, then, influences positively the development of green technology. Meanwhile, the reason for including the BRICs countries as a dummy is because these BRICs countries are in a unique situation of fast- economic and income growth. Their income level is assumed to be such that it does not meet the level in the Environmental Kuznet Curve (EKC) representing high income, which results in more concern for environmental welfare. However, they are quickly approaching this threshold. Therefore, their concerns about growth are most likely much higher than their concerns over the environment at present, but perhaps only for the immediate future. Hence, these countries may have a different response to environmental technology investment than either the low or high income groups.

We also consider unemployment rate and degree of democracy as other possible representatives of our welfare weight on profit. A high unemployment rate causes strong political pressure on material growth and prosperity, which might create new jobs, such that concerns over environmental technology development or desire for a cleaner environment would be held back. In addition, depending on the income level, and hence who we assume to be in the political majority, an increase in the degree of democracy may also affect our welfare weight on profit by increasing the political power of minority groups, such as environmentalists.

Furthermore we consider regional dummies that affect the welfare weight, perhaps by increasing the concern countries have over environmental protection. We categorize our 200 sample countries in 7 regions and see whether there are joint efforts to develop green technology in each region. We divide the regions as follows; North America (NOAME), Central and South America (CSA), Europe (EURO), Eurasia (EURA), Africa (AFRI), Middle East (MIDEA), and Asia and Oceania (ASIOCE). By having regional dummies in our panel data we expect to examine whether there are joint efforts to develop the green technologies through regional economic integration such as the North American Free Trade Agreement (NAFTA) and the European Union (EU). In other words, we assume that regional economic cooperation, which usually includes trade benefits, can increase attention for environmental protection. As an example, if a group of trading partners in one region with different concerns over the environment is trying to start a regional economic integration unit, a country with low-concern regarding the environment may follow the high standards of environmental protection set by the majority of the countries involved in order to enjoy the benefits of joining the group.

Lastly, we include four international environmental conventions and protocols dummies[8] as a final possible representation of our welfare weights. Obviously, a country's ratification of an international environmental convention suggests some heightened concern about environmental protection. However, Chau and Kanbur (2002) suggest that the determinants of ratification of international agreements are not always clear. In examining international labor agreements they find a strong peer effect, purporting the ratification of international agreements as strategic compliments. Hence, a country may ratify these international conventions do to strategic factors not indicative of their own environmental concern. Any interpretation of the empirical results of these international convention dummies, then, should consider the possibility of these outside influences.

3.3.2 Econometric Estimation

Given the choice of independent variables, our econometric panel model can be expressed as follows;

[8] Convention on Long-Range Transboundary Air Pollution(LRTAP),1979, Montreal Protocol on Substances That Deplete the Ozone Layer(MONT),1989, United Nations Framework Convention on Climate Change(UNFCCC), 1992 and Kyoto Protocol (KYOTO),1997

Degree of Technology = f (Unemployment rate, Degree of openness, Degree of Democracy, BRICs, High income countries , Non high income countries, Seven different regions and four convention dummies)

That is,

(3.1) $$CO2/GDP_{it} = \varepsilon_{it} + \beta_1 unemp_{it} + \beta_2 open_{it} + \beta_3 demo_{it} + d_1 BRICs + d_2 High$$
$$d_3 Non-High + \sum_{i=4}^{10} d_i regions + \sum_{i=11}^{14} d_i conventions$$

3.4 Data Analysis

Our independent and dependent variables for the panel consist of eight different variables. The data for these variables starts from 1979 when the first international environmental convention on air pollution was signed.

3.4.1 Dependent Variable

As for the dependent variable, we use metric tons of carbon dioxide emission from consumption and flaring of fossil fuels divided by thousand dollars of GDP.[9] It measures the amount of metric tons of CO2 emission per thousand dollars of output produced. Therefore, if CO2/GDP decreases (increases) we consider it as a result of an increase (decrease) of domestic investment to develop green technology. The summary statistics for CO2/GDP is as follows.

[9] Gross Domestic Product using 2000 U.S. Dollars

Table 3.1 Summary of CO2/GDP

Variable	Obs.	Mean	Std. Dev.	Min	Max
All countries	1367	.5486	.4631	.03	5.78
High-Income Countries	611	.5590	.3570	.19	2.44
Non-High Income Countries	756	.5402	.5337	.03	5.78
BRICs	58	1.150	.8613	.22	3.15

Source: Author's calculation using International Energy Annual (2006)

From the summary statistics above we can see that the average CO2/GDP ratio for high income countries is higher than that for non-high income countries. Meanwhile, BRICs shows higher CO2/GDP ratio than average CO2/GDP ratio for all countries. However, before comparing and analyzing the CO2/GDP level for different groups of countries, we should note that the data in this paper comes from the period 1979 to 2006. Therefore it is necessary for us to check whether there is tendency of increases or decreases of CO2/GDP ratio for the different groups of countries throughout this period. Below are the plots of CO2/GDP changes for 3 different groups of countries over the period from 1979 to 2006.

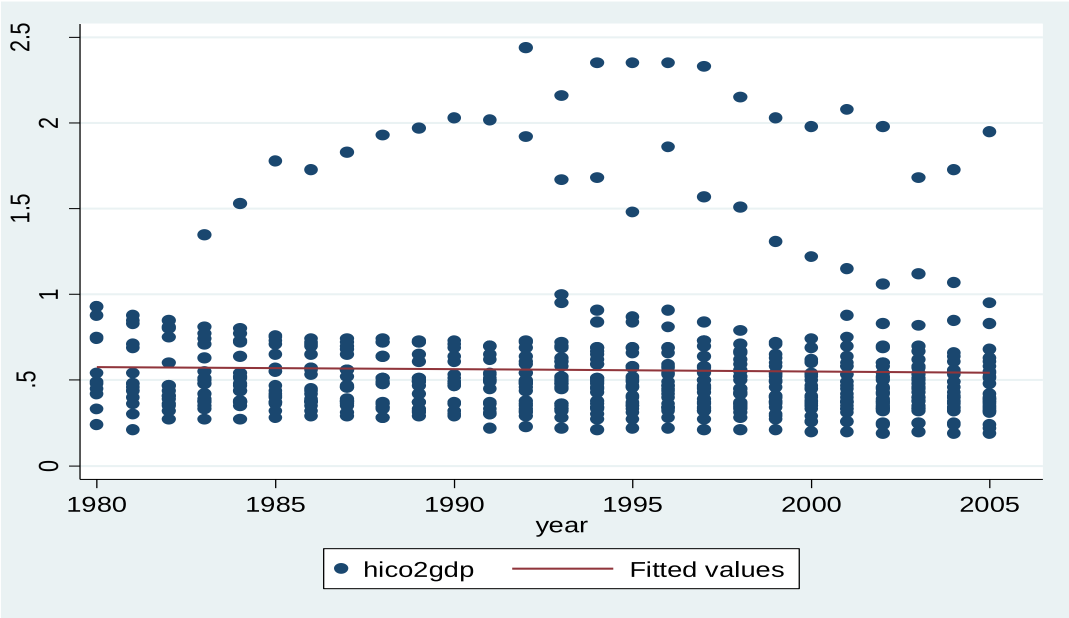

Figure 3.1 CO2/GDP change over time for high income countries

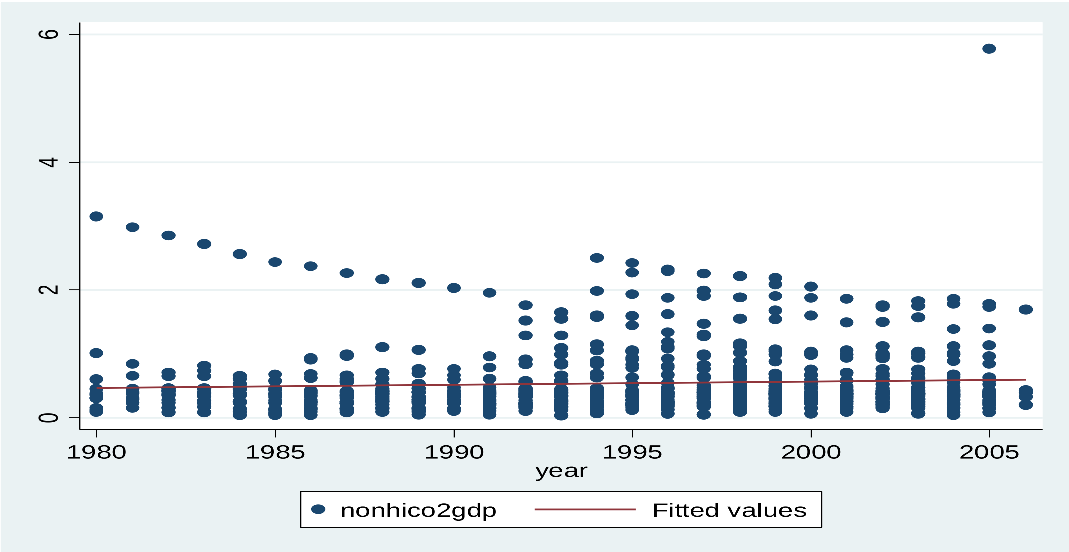

Figure 3.2 CO2/GDP change over time for non-high income countries

From Figure 3.1 and 3.2, we observe that CO2/GDP slightly decreases for high income countries and slightly increases for non high income countries. This implies that investment in green technology actually increased for high income countries from 1979 to 2006 and decreased for non high income countries during the same period.

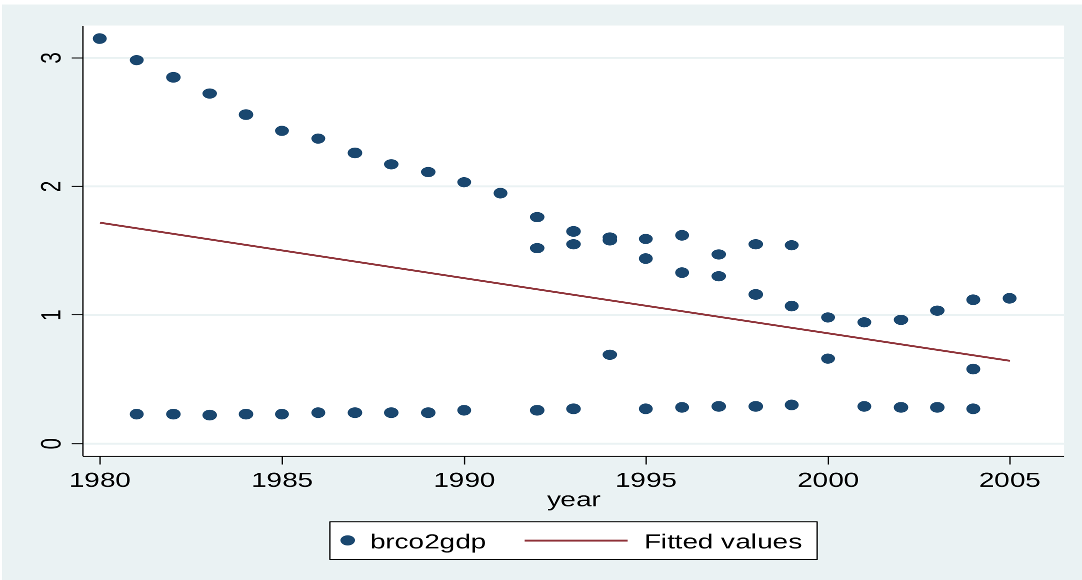

Figure 3.3 CO2/GDP change over time for BRICs

Although summary statistics show that the mean value of CO2/GDP for BRICs is larger than the average CO2/GDP ratio of all countries, Figure 3.3 shows that CO2/GDP for BRICs decrease over time. This implies that the effort to develop green technology actually increased for BRICs over time. This is significant since we consider BRICs as highly developing countries that are assumed to put more importance on growth rather than a clean environment.

3.4.2Explanatory Variables

Degree of Openness

As for the openness measure, we use two indices as mentioned above. First, we use the Sachs and Warner openness measure (SWOPEN) developed by Sachs and Warner (Sachs and Warner (1995)).This measure focuses on the political aspect of trade liberalization for 111 countries up to the year 1994. According to the authors, a country's trade regime is closed if it displays any of the following five criteria: (1) average tariff rates of 40 percent or higher; (2) non-tariff measures covering at least 40 per cent of trade; (3) a period average parallel market exchange rate premium of 20 per cent or more; (4) the existence of a state monopoly on major exports; and (5) a socialist economic system. When a country falls into at least one of the criteria, then it is indexed as "open", and if not, it is indexed as "closed". In addition, viewing a previous commitment to trade openness as a signal for the future, the data for Sachs and Warner openness measures were recorded as "open" through 2006 if they appeared as such in 1994. However, if a specific country was not open in 1994, we recorded as missing data after 1995 for that country.

Second, since Sachs and Warner openness measure is a dummy variable, we try to deploy a more dynamic openness measure (OPEN) than the Sachs and Warner measure that examines trade liberalization. This openness data is collected from the World Development Indicator (WDI)[10]. The data is calculated by adding up the export and import amount and dividing it with the real GDP for each country.

Although we use two different measures for the degree of openness, here we

[10]http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20398986~menuPK:64133163~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html

focus our analysis on the degree of openness that is measured by import and export amount as percentile of GDP (adding the raw amount of export and import then dividing into real GDP (2000 U.S. dollars)) mainly because our purpose here is to obtain a general idea of the relation between trade openness and clean technology level. The summary for the statistics of this openness measure is as follows

Table 3.2 Summary of Degree of Openness[11]

Variable	Obs.	Mean	Std. Dev.	Min	Max
Open General	1367	71.38	42.31	11.54	447.39
High-Income Countries	611	74.76	46.60	16.10	447.39
Non-High Income Countries	756	68.65	38.31	11.54	280.36
BRICs	58	34.39	18.60	14.39	110.57

Source: Author's calculation using WDI (2009)

From the summary statistics above we can see clearly that high income countries are much more liberalized than mid and low income countries in terms of trade. Also the BRICs countries that are assumed to have maintained more growth oriented policies than other countries do not seem to liberalize their market as high

[11] Here we use volume of import and export divided by real GDP (2000 U.S. Dollars)

income countries did. Thus, by these summary statistics we can expect that there might be different kinds of trade liberalization effects on developing green technology.

Although there is no consensus among existing literature on the relationship between trade and environment, we attempt to analyze the effect of our openness measure on green technology development by conducting simple OLS regressions.[12] Table B.1, B.2, B.3 and B.4 in the appendix shows OLS regression results for Sachs and Warner openness measures on developing green technology. First, as these tables show, the Sachs and Warner openness measure seems to have a negative effect on CO2/GDP ratio for all countries in general. It seems that our expectation for this openness measure is consistent with this OLS result.[13] In addition, our first finding seems to hold even if we divide our sample countries into 3 different country groups: high income countries, non-high income countries and BRICs. As for the high income countries, the coefficient of Sachs and Warner openness measure variable is (-0.7010). However, for the non-high income countries, OLS regression results show a much smaller slope of (-0.2908). This implies that the Sachs and Warner openness measure has a relatively strong positive effect on developing green technology for high income countries. This supports testable hypothesis 1: Opening trade derives incentives for countries to develop green technology. As for the BRICs countries, a negative relationship between CO2/GDP and Sachs and Warner openness measure seems to be confirmed again. In fact, the coefficient of this openness measure for BRICs on CO2/GDP is (-1.047), which is the steepest slope among these three country groups.

Second, as we can see in Tables B.4, B.5, B.6, B.7 and B.8 in the appendix, our other openness measure (import and export volume divided by GDP) seems to

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[12] Six different OLS regression results that consider the two different openness measures for 3 different country groups are reported in section B of the appendix

[13] We expect that trade liberalization gives rise to positive incentives to develop green technology for several reasons as we explained in the previous section.

have a negative effect on developing green technology. Also this negative relation seems to hold for three different country groups. It seems that for this particular openness measure, domestic political pressure for growth outweighed the effects of the other factors such as cultural spillover from using green technology or reducing the development cost by making easier access to green technology. Here again we take the income difference into account to find the general relationship between the degree of openness and clean technology level. According to Table B.6 and Table B.7 in the appendix, it seems that our finding from Table B.5 does change. This implies that income level plays a critical role in defining this relationship between openness and green technology levels. For instance, the coefficient of high income countries shows (+0.0017) while for non high income countries the coefficient for the same openness measure is (+0.0018). However, unlike Sachs and Warner openness measure the sign for its effect on developing green technology is consistently positive. Positive coefficients imply that this openness measure negatively affects the development of green technology. Also for the BRICs, the negative relationship between this openness measure and investment in green technology seems to hold as well. In fact, the relationship is more obvious in that the coefficient of regular openness measure is (+0.013).

This openness measure that depends on trade volume seems to support the pollution haven hypothesis unlike the Sachs and Warner openness measure. The more countries try to open their domestic markets, the more they try to occupy a competitive position in the international market causing them to avoid putting more weight on developing green technology to reduce carbon emission. However, for the Sachs and Warner openness measure, it seems that our theoretical findings from proposition 3 hold. That is, if green technologies are assumed to be more available countries try to develop green technology more rigorously. However, further details including robustness will be examined by considering the other variables so as to confirm the impact of the openness measures on the level of green technology development.

Unemployment Rate

Unemployment rate is another variable that may have affected the political decision to develop clean technologies by affecting the cost of development. Also as mentioned above, it indirectly reflects the lack of social stability that could provoke changes in the domestic policy on developing green technologies. For example, as the unemployment rate gets higher, domestic politicians could be affected by the voters who care more about least cost output expansion, which renders more jobs, rather than the environment. Therefore, given the fact that production cost increases as firms try to reduce carbon emission, it is expected that a higher unemployment rate would cause more pressure on growth rather than positively affecting a policy that leads to investing in the low carbon technology. The source of the data is again from the World Development Indicators (WDI) and the summary statistics of unemployment rate data for entire countries and for different country groups are as follows:

Table 3.3 Summary of Unemployment rates

Variable	Obs.	Mean	Std. Dev.	Min	Max
Unemp	1367	8.90	5.04	1	39
Hiunemp	611	8.16	4.17	2	24
Nonhigh	756	9.49	5.57	1	39
Bruemp	58	5.06	3.01	2	13

* Source: Author's calculation using WDI (2009)

As we can see from the summary statistics above, there are slight differences between high income countries and non-high income countries in terms of the unemployment rate. In addition, BRICs show quite a different scale, compared to other countries we considered. However, do the summary statistics necessarily imply that BRICs are more concerned about developing the green technology than the others in general?

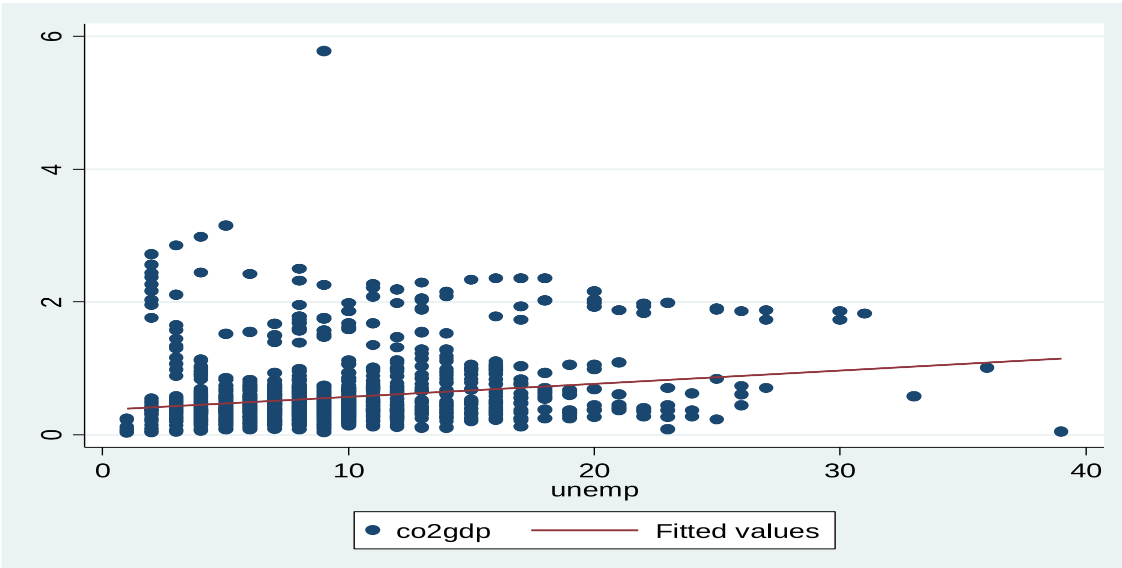


Figure 3.4 Unemployment rate for all countries and CO2/GDP

From figure 3.4, it appears that there is a positive relationship between CO2/GDP and unemployment rate. In other words, our assumption that a higher unemployment rate renders policy that places more weight on growth seems quite plausible. Also if we plot the relationship for both high and non-high income countries the overall negative relationship between clean technology and the unemployment rate does not seem to be changed. Figure 3.5 and Figure 3.6 show that the scatter plot is upward sloping implying that there could be a negative relationship between investing in green technology and the unemployment rate for countries with all different kinds of income levels.

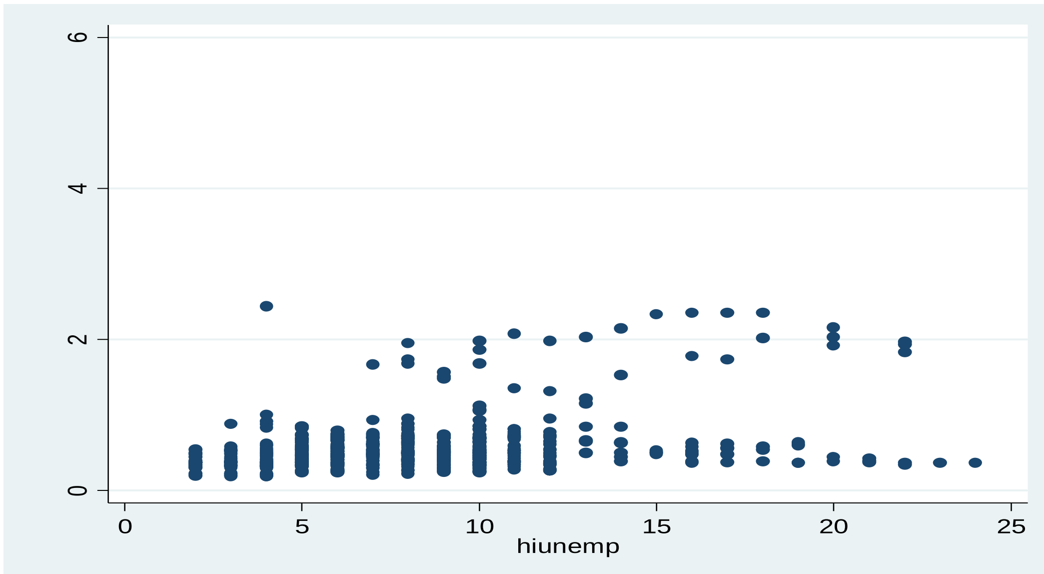


Figure 3.5 Unemployment rate for high income countries and CO2/GDP

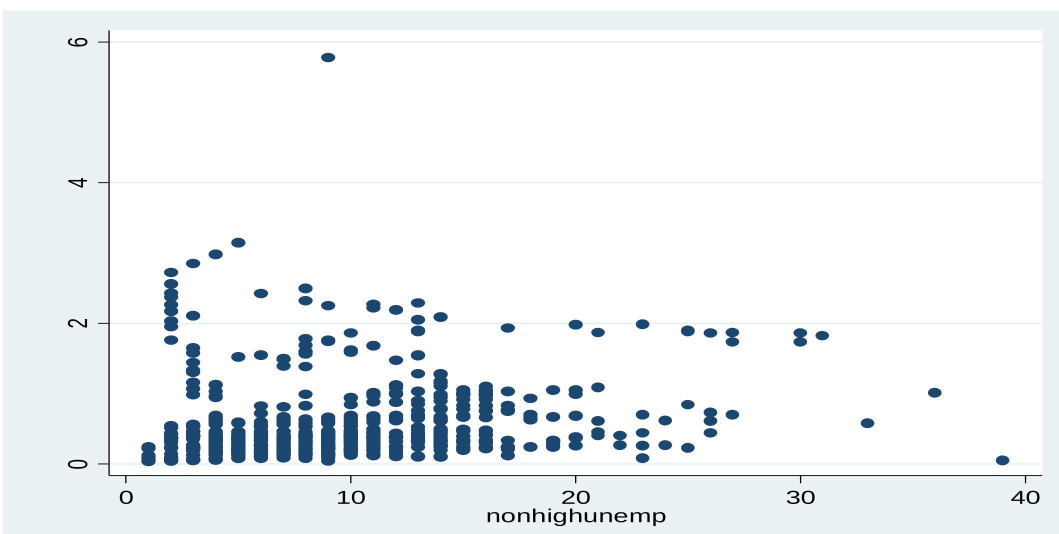


Figure 3.6 Unemployment rate for non-high income countries and CO2/GDP

However, we find an interesting result for BRICs countries. Recall that BRICs have an unemployment rate two times lower than other country groups as seen from the summary statistics. From Figure 3.7, unlike high income countries we observe that there is a positive relationship between the technology level and unemployment rate. This is not consistent with our premise; higher unemployment rate provokes political pressure that leads politicians to put more weight on growth so as to create more jobs.

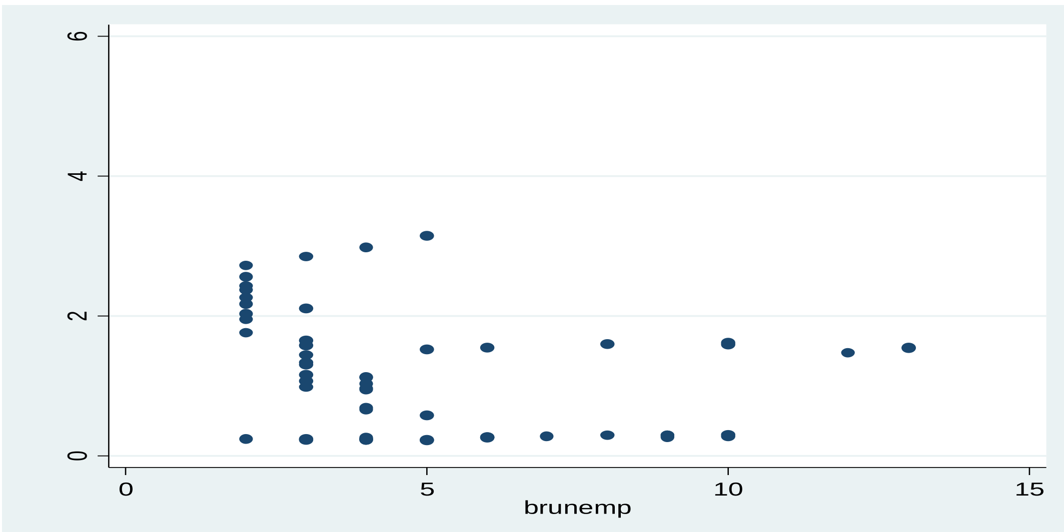


Figure 3.7 Unemployment Rate for BRICs and CO2/GDP

Regions

Regional dummies are chosen to measure the role of a incentive to develop clean technology as mentioned above. In other words, regional dummies are used to indirectly measure the welfare weights on both growth and clean air. For instance, from historical backgrounds or cultural religious reasons, the degree of national concern may differ by country or regions. Also political or economic integration by geographical regions such as EU or NAFTA could be another reason for specific regions to have a joint effort to develop clean technology to curb global warming. The degree of clean technology which is measured as CO2/GDP differs by regions as Figure 3.8 shows.

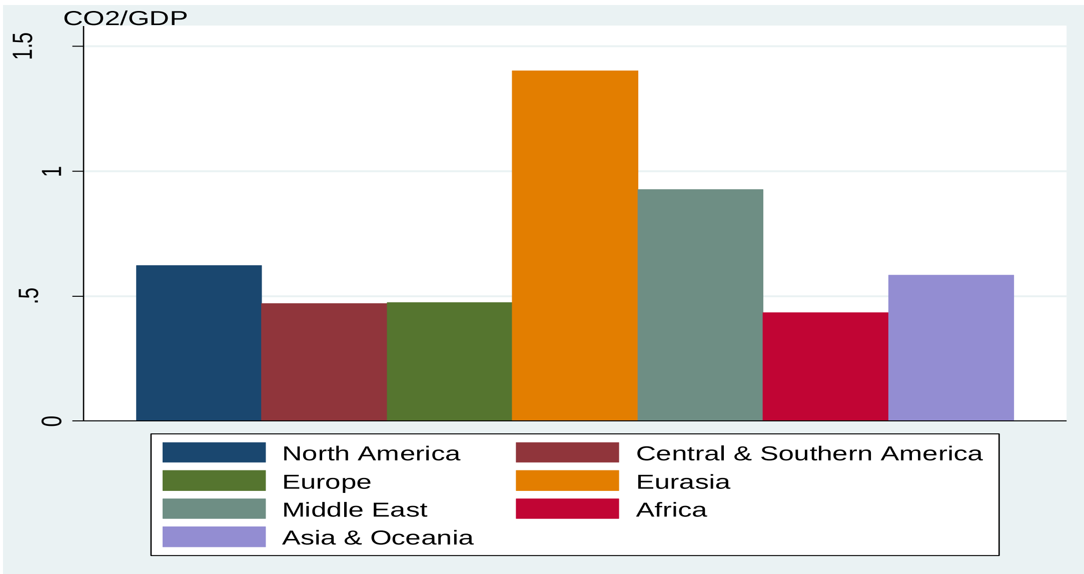


Figure 3.8 Mean CO2/GDP comparison for Seven Regions

Throughout twenty-six years, European, central and southern American and African countries showed relatively high CO2/GDP degree compared to other regions. Although this does not necessarily imply that those three regions were trying to invest in developing green technology, we can see that a difference between regions exists and it implies that there could be a joint effort on curbing CO2 emission. The summary statistics for different regions are as follows;

Table 3.4 Summary of Regional CO2/GDP difference

Variable	Obs	Mean	Std.Dev.	Min	Max
NOAME	68	.622	0.156	0.35	0.93
CSA	379	.471	0.444	0.08	2.35
EURO	471	.473	0.189	0.19	1.28
EURA	71	1.402	0.815	0.34	5.78
MIDEA	11	0.925	0.193	0.39	1.11
AFRI	119	0.432	0.498	0.03	1.99
ASIOCE	248	0.584	0.504	0.04	3.15

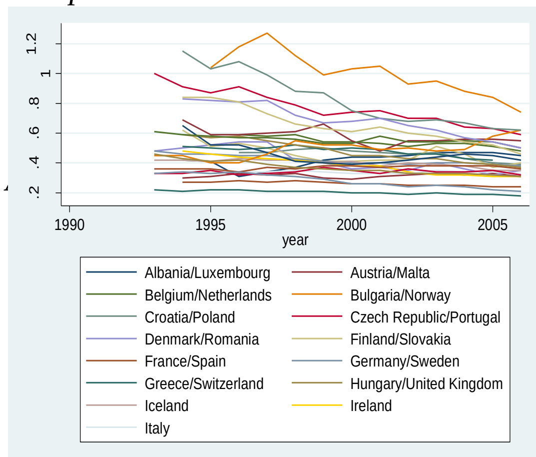
As seen in Figure 3.8, regional differences are clearly verified through comparing the mean CO2/GDP values. The peer effect of joint collaborative effort in terms of reducing CO2 emission will be verified through our panel data regression. However, we should note that these indexed dummies can mislead us to conclude that peer effects do exist if we merely consider the reduction of CO2/GDP value itself. Therefore it is necessary for us to consider CO2 emission by regions and their degree of economic development as well. For example, if a specific region has a particularly low amount of CO2 emissions and is relatively less developed for a sufficiently long period of time, the panel regression may give a spurious result falsely implying that the region has been continuously developing green technology.

Convention Dummies

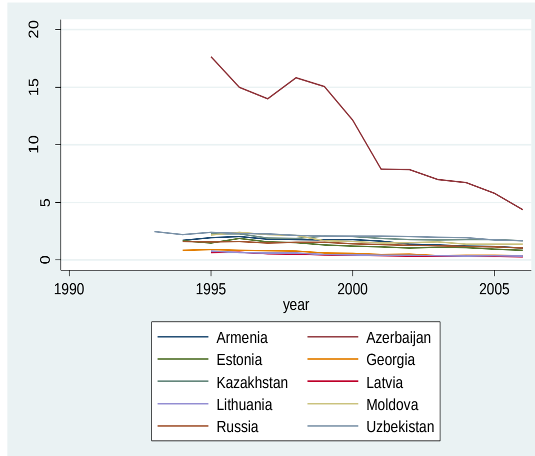
Convention dummies are deployed to measure the importance attached to environmental concerns. Therefore, the ratification of the conventions would be an indirect way to signal that one country is allocating domestic resources toward developing technology. However we should be careful in our use of these dummies. If ratifications can be regarded as strategic complements for most of the countries, the information gained from these dummies may not represent impacts of greater environmental concern (Chau and Kanbur (2001)). We further consider this issue when we interpret the econometric results in the next section. The following graphs depict how countries have performed after the most recent major environmental conventions, such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol, were ratified. Figure 3.9 shows the variation of CO_2/GDP level over time by seven regions considered. We can attempt to approximately tell what region or countries have taken the convention into account in their policies leading them to invest in the green technology.

First of all, there are several countries showing the CO_2/GDP ratio decreasing rapidly in the European region. This presents the fact that many European countries have been making significant efforts on technological advancement since the ratification of UNFCCC. However, this generalization is only limited to the European region since there are not many prominent changes among other countries in different regions. In particular, it is obvious that the ratification has not been successful when it comes to leading changes in Africa, Middle East, and Asia. Contrary to this insignificant ramification of the ratification among those regions, there are dramatic changes in North America. Aside from the fact that the graph of the region displaying the effect of the ratification looks outstanding due to its relatively small number of countries included unlike other regions, it is clear that the US and Canada have been trying to develop their technology markedly.

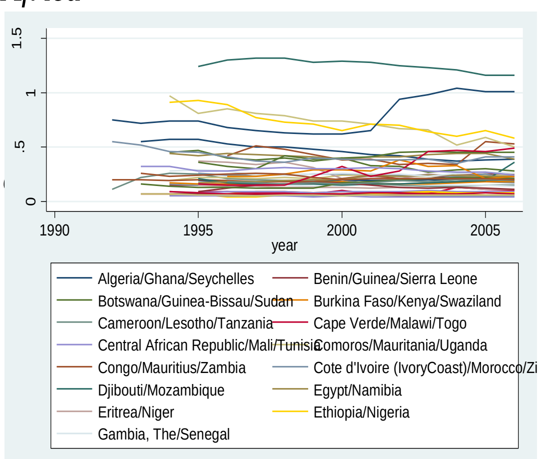
European



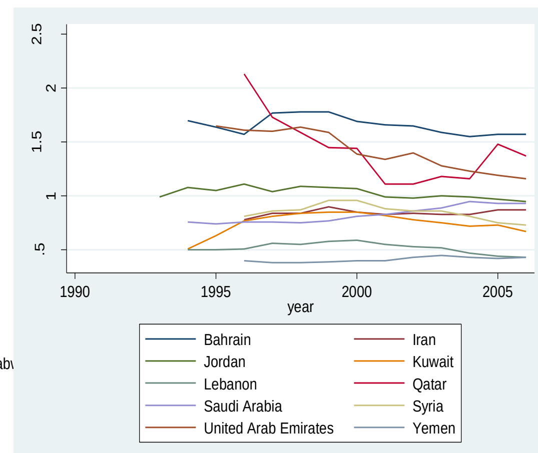
Eurasian



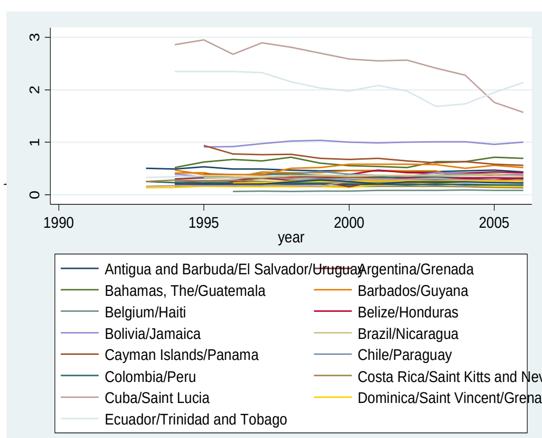
Africa



Middle East



Central & Southern America



Asian & Oceania

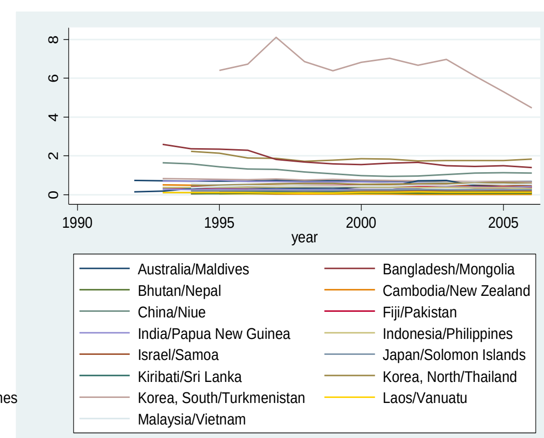


Figure 3.9 CO2/GDP change after ratification of UNFCCC

Figure 3.9 (Continued)

North America

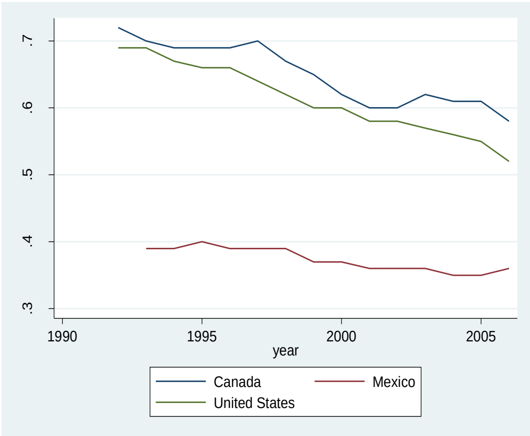


Figure 3.10 outlines the change of environmental technology level by region and by country over time since ratification of the Kyoto Protocol. One prominent observation from this figure is the fact that it displays the progress in technology among European and North American regions. The fact that North American region shows progress in green technology development is hard to ignore because the US has not ratified the Protocol by now. Therefore, it is doubtable whether the Kyoto Protocol has indeed influenced the policy regarding environmental protection. To confirm this, a careful experiment on statistical significance of the Kyoto Protocol will be presented in the later chapter of this paper by using Panel regression.

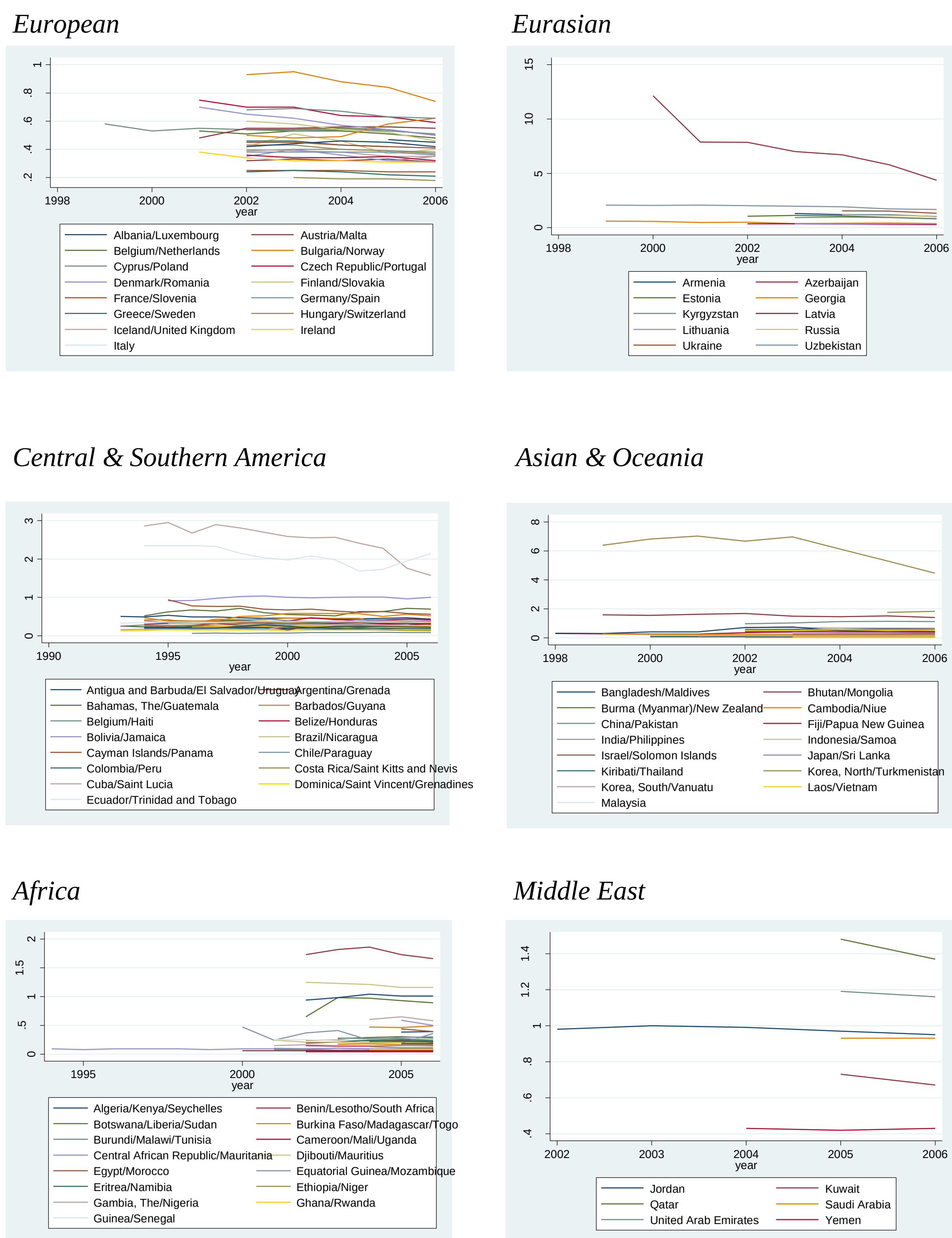
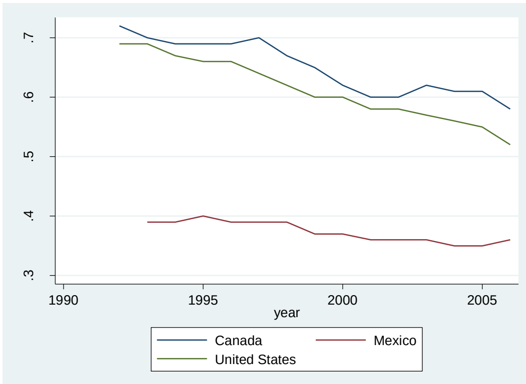


Figure 3.10 CO2/GDP after ratification of the KYOTO protocol

Figure 3.10 (Continued)

North America



Degree of democracy

The degree of democracy in this paper is a variable, which estimates the cost of developing green technology, not from a technical standpoint but rather with respect to the costs necessary to implement new policies. In other words, the higher degree of democracy is associated with more thorough domestic policy analysis which requires careful consideration of all possible viewpoints, resulting in greater research on the relationship between environmental regulations and economic development. Specifically, it might cost more when development-oriented politicians command a majority among the decision makers, because the opportunity cost for collecting views from the minority is significant. On the other hand, we consider degree of democracy as one of the variables that affects welfare weight on profit. This is because increase in degree of democracy may also affect domestic welfare weight on profit by enhancing chances to reflect the opinions of political minorities. Therefore when degree of democracy increases in a country where political minorities are environmentalists, it leads development-oriented politicians to decrease the investment in green technology because of the opportunity cost for collecting views of the minorities which affects green technology development cost, but at the same time it leads them to increase the investment in green technology because of the enhanced chances for the minorities to affect policy makers. The data for degree of democracy is from Polity IV Project[14], and the summary statistics for degree of democracy is as follows;

Table 3.5 Summary of degree of democracy

Variable	Obs	Mean	Std.Dev.	Min	Max
Demo	1367	6.51	5.46	-10	10
Highdemo	611	9.63	1.29	-2	10
Nonhighdemo	752	4.02	6.22	-10	10
Brdemo	58	-0.344	6.92	-7	9

* Source: Author's calculation using Polity IV Project (2009)

As presented in the table above, high-income countries record a higher degree of democracy compared to the degree of low-income countries. Let us take a look at the relation between the degree of democracy and environmental technology level of the high-income countries. As seen in Figure 3.12 through Figure 3.15, high-income countries show a relatively steep slope in the linear fit. Unlike non-high income countries, the data reveal a clear correlation between political freedom and clean technology level among high-income countries. The BRICs countries also show a

[14] Political Regime Characteristics and Transitions, 1800-2007.
(The Polity IV Project carries data collection and analysis through 2007 and is under the direction of Monty G. Marshall at the Center for Systemic Peace and George Mason University)
See website http://www.systemicpeace.org/polity/polity4.htm

similar correlation with high-income countries and, which results from their domestic pressure on economic development. More results will be examined later through our panel regressions. Although much of the literature[15] has been making an effort to define the relationship between environment and political variables, there has been no consensus yet on the statistical causality.

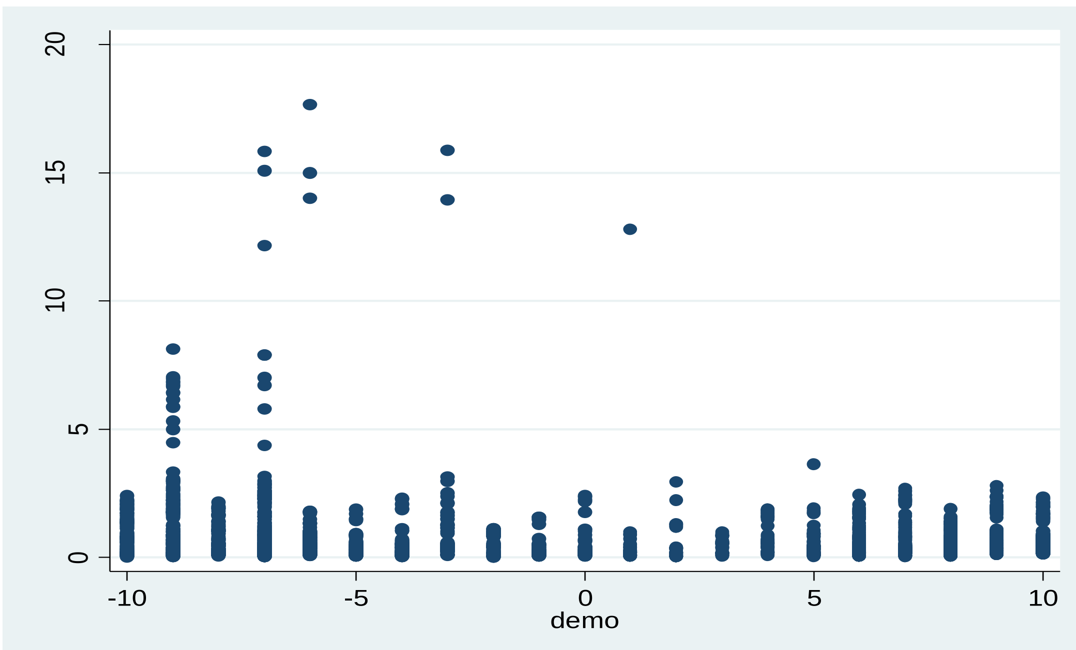


Figure 3.11 Degree of democracy for all countries and CO2/GDP

[15] Torras and Boyce (1998) used political rights and civil liberties for both high and low income countries as independent variable to estimate the determinants of SO2 emission. Also, Carlsson and Lundstroem (2006) used political freedom to estimate the determinant of CO2 emission. Both of them did not find statistically significant effect on their dependent variables.

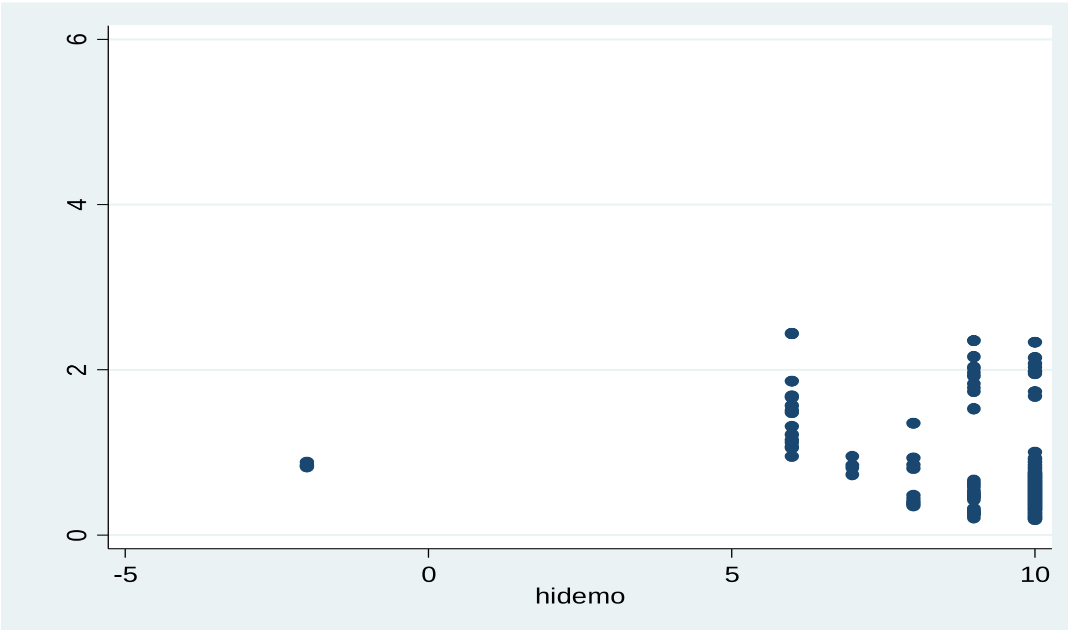


Figure 3.12 Degree of democracy for high income countries and CO2/GDP

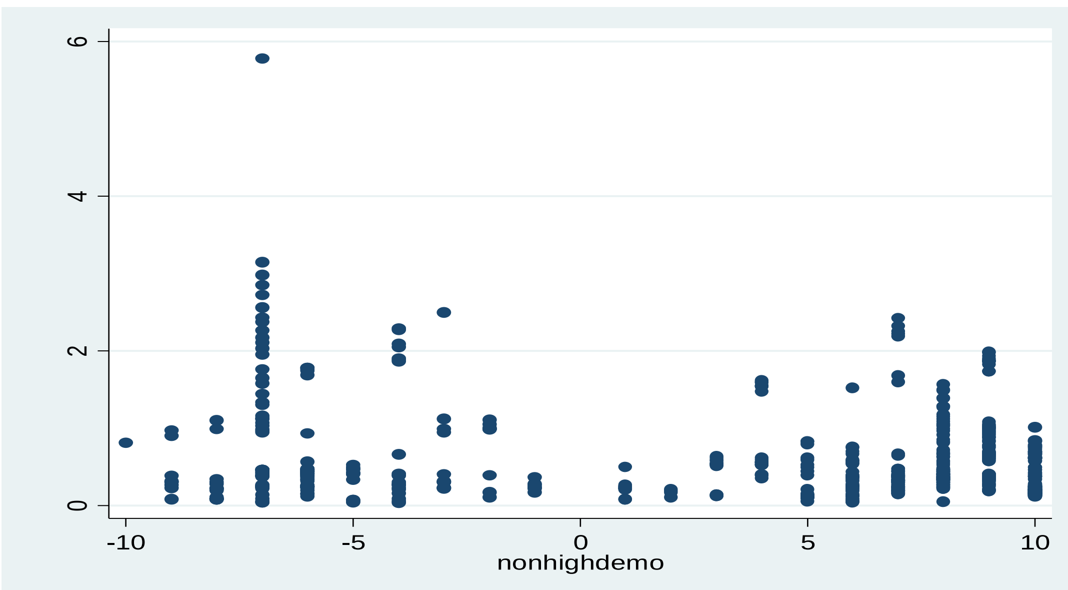


Figure 3.13 Degree of democracy for non-high income countries and CO2/GDP

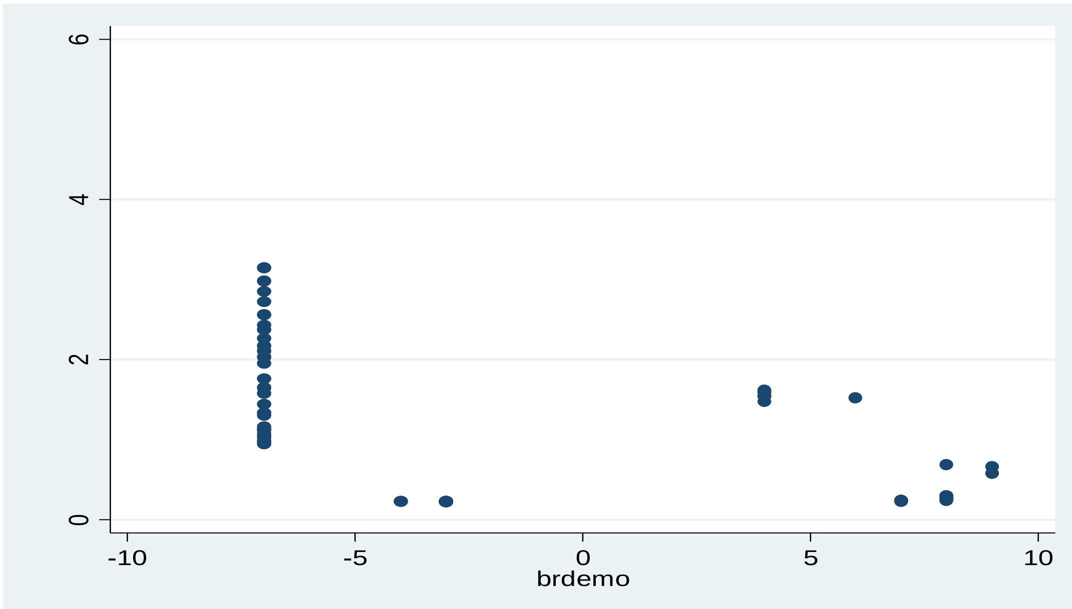


Figure 3.14 Degree of democracy for BRICs and CO2/GDP

3.5 Results

Recall the estimating equation (3.1).

$$CO2/GDP_{it} = \varepsilon_{it} + \beta_1 unemp_{it} + \beta_2 open_{it} + \beta_3 demo_{it} + d_1 BRICs + d_2 High + d_3 Non-High + \sum_{i=4}^{10} d_i regions + \sum_{i=11}^{14} d_i conventions$$

Before estimation, we conduct tests to check the OLS assumptions of multi-collinearity, normality, heteroskedasticity, and autocorrelation. It is revealed that heteroskedasticity and autocorrelation are our only violations[16]. We also consider the possible case of non-stationarity for every variable, which could have caused

[16] All tests to check OLS assumptions are reported in section A of the appendix.

inconsistency in our estimators and resulted in a spurious regression. In addition, computed F-test for the interaction with dummy variables suggests that they do indeed have some explanatory power.[17] Furthermore, the Hausmann specification test to evaluate models with random effect and fixed effect was conducted. We find that the random effect estimation fits our model better.

We assume that all countries in our panel data set have the same degree of effect on green technology development dynamics from our chosen independent variables that we listed above. Since we found out that our panel data set had autocorrelation of degree one and heteroskedasticity, we try to correct both of these problems by deploying Newey West standard error correction method. The Newey-West (N-W) Least Variance Estimation is usually conducted for the models where FGLS is not feasible to obtain unbiased and consistent estimators. Since our FGLS with AR (1) model has failed to render a consistent and unbiased estimator, it is necessary to deploy this method to obtain such estimators. We try to explain our pooled model using the pooled regression result that has been corrected with the N-W method. Also, for the panel regression, we conduct both the country fixed model and random effect model. However, as seen in the Hausman test result, a fixed effect model offers somewhat limited and less consistent information to support our findings. According to Hausman specification test which is presented in Table 3.6, the fixed effect model [18]may render biased outcomes relative to the model that considers all variables that we are interested in. We focus our analysis on pooled model and the random effect model.

[17] F-test results for interaction variables are reported in section D of the appendix.
[18] Results for Fixed effect models are reported in the section C of the Appendix.

Table 3.6 Specification test for the base model[19]

	Specification	CO2/GDP
Hausman Test ($\chi 2$)	Country specific	14.10 (0.070)
	Year specific	7.82 (0.098)

Note: p-values are in parentheses.
Testing Hypothesis: Hausman Test H0: random effects, H1: fixed effects

Table 3.7 Regression results for Pooled model and Random effect model

	Pooled		**Random**	
Variables	Coeff.	Std.E.	Coeff.	Std.E
UNEMP	0.027***	0.003	0.001***	0.000
SWOPEN	-0.111***	0.041	-0.013*	0.007
DEMO	0.002	0.004	0.0001	0.000
BRUNEMP	- 0.030	0.028	-0.022*	0.011
BRDEMO	-0.089***	0.020	-0.025***	0.008
BROPEN	-0.003	0.006	-0.001	0.001
HIUEMP	-0.004	0.006	0.001	0.001
HIDEMO	0.012**	0.006	0.004**	0.001
HIOPEN	0.001***	0.000	0.0007***	0.000
BRICS	0.959***	0.227	0.619***	0.102
NOAME	0.111***	0.033	0.145***	0.024

[19] The Hausman test tests the null hypothesis that the coefficients estimated by the efficient random effects estimator are the same as the ones estimated by the consistent fixed effects estimator. If they are insignificant, then it is safe to use random effects.
Independent variables for base model are; UNEMP, SWOPEN, OPEN and DEMO.
OPEN is excluded in our extended model to avoid multicolinearity with the interaction variables such as BROPEN and HIOPEN.

Table 3.7 (Continued)

CSA	-0.031	0.050	-0.070***	0.019
EURO	-0.184***	0.047	-0.044***	0.016
EURA	0.824***	0.139	0.892***	0.085
MIDEA	0.306***	0.076	0.526***	0.103
AFRI	-0.091	0.059	-0.103***	0.020
IRTAP	0.053	0.037	-0.009	0.008
MONT	-0.018	0.038	-0.005	0.004
UNFCCC	-0.034	0.042	-0.008**	0.004
KYOTO	-0.004	0.036	-0.012***	0.004
Const.	0.291***	0.056	0.399***	0.016

Source: WDI (2009), Sachs and Warner (1995), IEA (2006) International Environmental Agreements database Ver. 2007.1 and
Political Regime Characteristics and Transitions, 1800-2007 (2009)
***, ** and *denote significance at 1 percent 5 percent and 10 percent level respectively
Note; 1) BROPEN, BRDEMO and BRUNEMP denote the interaction variable between BRICs and three dependent variables; Openness, Degree of democracy and Unemployment rate
2) HIOPEN, HIDEMO and HIUNEMP denote the interaction variable between high income countries defined by UN and three dependent variables; Openness, Degree of democracy and Unemployment rate
3) CO2 is measured in Metric Tons and real GDP is Thousand 2000 U.S. Dollars

3.5.1 Degree of Openness

For the Sachs and Warner openness measure, our empirical results show that the level of technology increases as countries decide to open their economies more to the international market. On the other hand, the regular openness measure (amount of export and import divided by real GDP) shows that the level of green technology decreases as countries decide to open their economies.

Therefore, our results for the Sachs and Warner openness measure do not support the pollution haven hypothesis that has been supported by recent literature (Mani and Wheeler (1998)). Although it is beyond the scope of this paper to examine whether the hypothesis is right, since it is virtually impossible to obtain micro industry data at the firm level that can prove which industry has a relative advantage in producing products using “dirty” technology, it seems that trade in general has a positive effect on cleaning the pollution as argued by other strands of literature. (Grassebner, Lamla and Strum (2006))

Also, our result shows the net effect of openness on green technology development. Using the Sachs and Warner openness measure, we can see that global consciousness on the environment outweighs the domestic pressure of growth although the availability of green technology makes these objectives compatible. This implies that as the degree of openness increases there is cultural spillover or cultural exchange that affects the domestic focus on the environment. Furthermore, this supports our assumption that trade liberalization affects the cost of developing green technology by providing countries easier access to green technology.

However, when it comes to trade volume divided by GDP openness measure, we find different results. For example, high income countries show the opposite sign and BRICs show no statistical significance for both the pooled and random effects models.

Several factors have influenced these effects of the openness measure on green technology development. First, the trading partners for BRICs countries were not as diverse as developed countries. This implies that if the major trading partners are the ones that do not require rigorous environmental standards it may reduce the incentive to develop green technology. According to the Direction of Trade statistics Yearbook by the IMF, major trade partners of BRICs were developed countries such as the United States (IMF (2005)). In fact, except for Russia whose major trading partner was the European Union, all BRICs countries traded most significantly with the United States, one of the largest carbon gas emitters. However, in recent years the BRICs countries have been trying to diversify their trading partners. According to the Comparative Analysis of the BRICs by the Economic and Social Research Institute (ESRI (2006)), all BRICs have increased their trade with neighbor countries. Brazil made an effort to increase coordination with Latin America through initiatives such as the establishment of the South American Summit and the reinforcement of MERCOSUR[20], a regional Trade Agreement among Argentina, Brazil, Paraguay and Uruguay. Russia tried to promote regional economic integration through CIS[21] economic alliance, a unified economic zone with Ukraine, Belarus and Kazakhstan, and the Eurasian Economic Community. India tried to ratify bilateral and multilateral free trade agreements with the Association of Southeast Asian Nations (ASEAN). India showed progress of developing trade agreements with countries outside the region such as South Korea, Japan and China. Lastly, China concluded a free trade contract with ASEAN and Far East Asian countries in order to formulate and reinforce regional economic integration.

Also, an effort to reach regional economic integration by BRICs is still ongoing and may displace the United States as the group's main trading partner. Thus, the transformation of the trade pattern may result in a different test result for our

---

[20] MERCOSUR implies Southern Common Market in English.

[21] Commonwealth of Independent States is a regional organization whose participating countries are former Soviet Republics.

regression. On the other hand, high income countries are relatively diversified in terms of their trading partners, which consist of a wide range of countries outside the BRICs group. This implies that they have to follow more rigorous environmental standards in order to maintain their status in the output competition market.

In addition, we should note that we use a different openness measure for those two different country groups largely because of the multicollinearity problem for the interaction between dummy variables. This degree of openness measure[22] for BRICs and High income countries may be different from that of the Sachs and Warner openness measure since it mainly measures volume of export and import and does not take into account other openness standards such as the five criteria for the Sachs and Warner openness measure. Therefore, in order to compare the result from using the Sachs and Warner criteria, both country groups may need to consider other political aspects in addition to the export and import amount (i.e. five criteria of Sachs and Warner measurement). However, since the focus of our paper is to give a general idea of the role of the openness measure on technology development, we will not attempt to go further.

3.5.2 Unemployment

Our results for both pooled and random effects show that an increase in unemployment rate has a negative association on developing green technology. This supports our hypothesis that high unemployment rate causes political pressure on growth so as to create new jobs. Many researchers have studied the relationship between the social and political variables and the environment. Particularly, social or

[22] Volume of export and import divided by GDP

political instability has been the major variable in the empirical models of this literature. For instance, according to the recent empirical studies that considered inequality variables, such as the GINI ratio, as a proxy for social instability, social inequality contributes to the generation of pollution (Grassebner, Lamla and Strum (2006), Ravallion et al. (1997)). Just like the GINI ratio, unemployment could be interpreted as a sign of social instability in that both result in policy reforms.

We may consider the possibility that as social instability, represented as unemployment, increases in a country, the country tends to put more emphasis on economic growth rather than a clean environment. According to our study, however, there is no statistical significance in the country group dummies except for BRICs. Therefore, it is premature to say that there is a negative relation between unemployment and the investment in clean technology development. To put it another way, we cannot conclude that unemployment in one country causes political constraints regardless of economic development levels.

3.5.3 Regional Peer Effect

Statistically significant results have been discovered in five out of seven regions in our study. Among these five regions, which include the European, Eurasian, Central and Southern America, African and Asian/Oceania regions, the positive regional peer effect on technology development appeared only in European, Central and Southern American, and African regions. It seems that results for these five regions are consistent with our hypothesis that regional dummies may affect a country's welfare weight on the environment. Also the results possibly imply that there are cooperative efforts to develop green technology.

Although the European region as a whole consists of both developing and developed countries, the majority of OECD and high-income countries are included in the region influencing the result considerably. If we assume that the Environmental Kuznet Curve (EKC), the inverted U shaped curve representing the relationship between growth and environmental pollution, exists, then the EU's composition primarily of wealth countries implies that this region should have an overall focus on environmental issues. Moreover, the characteristics of highly developed economic integration in the region, in the form of the EU, should have provided less environmentally conscious countries in the region with enough incentives to cooperatively develop the clean technology.

Contrary to the European region, both the Central and Southern America region and the African region consist mainly of less developed countries where the absolute level of green technology is relatively low, as shown in the Figure 3.9 and 3.10. Therefore, even if both regions showed positive peer effects on developing clean technologies, it is risky to immediately come to this conclusion, since their low economic development level is strongly linked to their low carbon emissions. Meanwhile, the Middle East region and Eurasian region where less developed countries are the majority showed less tendency to develop the green technology.

Besides the degree of development, however, there are more factors to consider regarding regional peer effects on developing green technology. Data for major trading partners, and major exporting and importing sectors should be also incorporated and considered together. As an example, many countries in the Middle East region would tend to export their primary resource, mainly oil, which is a major source of the CO2 emission. Therefore, those countries have less incentive for green technology development and major trading partners who import oil from those countries cannot put pressure on them, regardless of their own opposite high domestic standard on environmental regulations.

Nevertheless, the intuition behind what we found from our regional dummies is that if international trade occurs more frequently within the region through regional economic integration or Free Trade Agreements, and if that region has relatively high environmental standards, then there is a possibility of having regional joint efforts to develop green technology not only to benefit from the clean air but also to reduce the cost of production.

3.5.4 Convention and Protocol dummies

As mentioned, the convention and protocol dummies are deployed to measure the effects of ratification of the convention. As we stated earlier, it is regarded as a commitment to use resources to curb emission of greenhouse gases. While there were no significant convention dummies found in our pooled model, the random effects model has presented statistical significance for some conventions and protocols. Two out of four conventions, the UNFCCC and Kyoto Protocol, showed that they actually have induced a positive effect on the development of green technology. We should however be careful interpreting this result since convention dummies are likely to lose information content over time if ratification for each country becomes strategic complements (Chau and Kanbur (2002)). In Chapter 2, we examined a case where technological investment of each country can be regarded as strategic substitutes. However, it was valid only when the welfare weight on profits is 1 and green technology prevails. If the welfare consideration of clean environment counts, it may well be the case that countries' ratification of environmental conventions and protocols can become strategic complement. Hence, we consider our results with the knowledge that ratification of these environmental conventions may not necessarily reflect a country's overall concern for the environment.

3.5.5 Degree of Democracy

As mentioned, the Degree of democracy (DEMO) has two different alleged causal impacts on the development of clean technology causing controversies within the literature. One of our assumptions is concerned about the extent to which the degree of democracy affects the cost of developing green technology. Transaction costs are generated when politicians try to encompass the opinions of minorities, and the influence of degree of democracy on developing green technology depends on who makes up that minority. The other assumption is that aside from the linkage between degree of democracy and the cost, democracy itself may influence the social welfare weight on profit or environment directly by enhancing chances for political minorities to reflect their opinions.[23]

It is not easy to figure out the underlying mechanism. In fact Carlsson and Lundstrom (2003) found no relationship between the CO2 emission and political freedom. Our results do not strongly support any hypothesis in general, however, for the case of the developed countries (HIGH) or highly developing countries (BRICs) there are certain noticeable statistical signs favorable for developing the low carbon emission technology.

If we assume that political minorities for both country groups are

[23] Therefore, if we assume that political minorities are environmentalists, increase in degree of democracy implies 1) negative effect on developing green technology by increasing development cost of the technology 2) positive effect on developing green technology by raising chances for minorities to reflect their opinions on domestic policy.

environmentalists, it seems that the net effect of both influence on developing green technology showed differently for both high income countries and BRICs. For high income countries, the negative effect by increase in cost of developing green technology seems to dominate the other effects. As for the BRICs it seems that the minority opinion of environmentalists is well reflected when the degree of democracy develops.

Chapter 4

CONCLUSION

Many existing studies have pointed out various amendments that should be considered in order to enhance the function of existing international environmental conventions. Following Barret (2006), this paper recognizes the importance of green technology to counteract global warming, and investigates the strategic role of government in technological investment in the global economy. In fact the paper attempts to provide a theoretical and empirical background to discuss this important hypothesis on technological response to climate change in a more general framework. We examine the individual incentives for free riding in reducing global warming as well as profit incentives to strengthen competitiveness in the international output market. We show that depending on the shape of the social welfare function, and the availability of green technology, a profit incentive can reinforce other incentives to clean the environment. In other words, countries do have an incentive to invest in R & D for clean technologies in order to occupy an advantageous status in international output competition. Since the investment incentives lessen the free riding incentives that prevail in the absence of green technologies, we characterize features of countries which have invested in clean technology in a relatively intensive way.

According to our theoretical propositions, the level of technology depends on the degree of openness, the cost of technological development and the welfare weights each country places on economic profits and the environment.

We specify an econometric model to test the relative importance of these variables through panel data. First of all, we find the degree of openness is related to the degree of the green technology development. We find that countries that have been under high growth pressure do not necessarily confirm this relationship. However, when we consider the different openness measurement, the Sachs and Warner openness measure, it seems that degree of openness is positively related to the development of green technology.

The unemployment rate, meanwhile, is negatively related to green technology development. However, this variable also shows a different relationship in our different country groups. In fact, we did not find any robust relationship between unemployment rate in BRICs or high income countries.

Interestingly, the regional peer effort of developing green technology seems to exist in certain regions. The intuition behind our result is that the more the region is comprised of wealthy countries whose welfare weights on the environment are high, the more the region tends to develop the green technology. For instance, we find that the European region with shared cultural heritage shows a positive peer effect on developing the green technology. However, we find the opposite effect for the North American Region. The statistical relationship between these variables may suggest a causal impact from belonging to one of these groups, such as pressure elicited from larger countries in the group to adhere to their environmental beliefs. However, it may only reflect a mere associative relationship, such that North American countries tend to care less about the environment while European countries have greater concern. Further analysis should examine the effect of this regional clustering on strategic investment policy.

Given their importance to international climate concerns we also examine the effect of the major convention dummies that countries have signed and ratified. However, only two out of four dummies are statistically significant and both of them show a positive effect on developing green technology. Further research to examine the peer effect should be conducted to confirm the reason why only two conventions are significant. The information content of convention dummies needs to be clarified further as previous literature has identified the possibility of countries' ratification of international conventions as strategic complements.

In addition, we considered the degree of democracy an important variable that influences the cost of clean technology investment. As a growing amount of research has pointed out, any relationship between pollution and political freedom is quite controversial. As expected we could not find the relationship between pollution reducing technology and political freedom. However, for the high income countries and highly developing countries such as BRICs significant results are found. In fact, they show totally different effects on technology development. For BRICs countries we find that the degree of democracy promotes the development of green technologies. High income countries, however, show the opposite result.

Finally, we would like to point out that empirical findings need further elaboration in the future. They can be considered as background material to evaluate the development incentives of green technologies for sustainable growth in the global market. Therefore, we need to address shortcomings of the theoretical propositions that are used as a basis of our empirical test. Particularly, the model needs to be further extended by incorporating a more general strategic situation such as a leader-follower case. The model also needs to incorporate tax policy, since government tax policy toward global warming play an important role in international efforts to prevent climate change. These tax policies influence the costs and benefits of developing green technologies. Finally, the social welfare function may not be sufficiently smooth and well shaped in important decision variables. We however leave the analysis of an extended model for a future research project.

APPENDIX

A. Test for OLS assumption

In this section, we attempt to confirm that our final model satisfies all the OLS assumptions.

A.1. Multicollinearity

We start by examining existence of multicollinearity. If samples have high multicollinearity, the model might encounter insignificant t ratio, a higher R^2 value, wrong signs for regression coefficients, unstable OLS estimators, and a difficulty in assessing the individual contributions of explanatory variables to the explained sum of squares or R^2. Auxiliary regressions and variance inflation factors help to determine if harmful collinearity is present.

Since multicollinearity occurs because one or more of the explanatory variables are roughly linear combinations of other explanatory variables, regressing each variable on the remaining variables help indentify if these linear combinations exist. If the variables in the final model do not have serious corrlelation we may use all the variables in the final model. However, if there is serious linearity among some variables we would have to eliminate or transform the trouble making variable from the model.

Table A.1. OLS result for Final model (Auxiliary regression) and VIF layout

Source	SS	df	MS
Model	135.093983	20	6.75469915
Residual	157.875741	1346	.117292526
Total	292.969724	1366	.214472711

Number of obs =	1367
F(20, 1346) =	57.59
Prob > F =	0.0000
R-squared =	0.4611
Adj R-squared =	0.4531
Root MSE =	.34248

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
brunemp	-.0307886	.0205436	-1.50	0.134	-.0710896	.0095123
brdemo	-.0895516	.0093038	-9.63	0.000	-.1078031	-.0713001
bropen	-.0039575	.0027612	-1.43	0.152	-.0093742	.0014592
hiunemp	-.0004712	.0040839	-0.12	0.908	-.0084827	.0075403
hidemo	.0125972	.0049534	2.54	0.011	.00288	.0223145
hiopen	.0015395	.0002879	5.35	0.000	.0009747	.0021043
brics	.9597565	.1248439	7.69	0.000	.7148467	1.204666
demo	.0023091	.0026427	0.87	0.382	-.0028752	.0074934
noame	.1116898	.0491074	2.27	0.023	.0153545	.2080252
csa	-.0316569	.0328283	-0.96	0.335	-.096057	.0327433
euro	-.1843513	.0323565	-5.70	0.000	-.247826	-.1208767
eura	.8247156	.0516031	15.98	0.000	.7234843	.9259469
midea	.306767	.112337	2.73	0.006	.0863923	.5271417
afri	-.0913891	.0451527	-2.02	0.043	-.1799664	-.0028117
irtap	.0534599	.0232557	2.30	0.022	.0078385	.0990814
mont	-.0183818	.0288553	-0.64	0.524	-.074988	.0382245
unfccc	-.0349287	.0271027	-1.29	0.198	-.0880969	.0182395
kyoto	-.004039	.028062	-0.14	0.886	-.059089	.051011
unemp	.0272084	.0025612	10.62	0.000	.0221841	.0322327
swopen	-.1111967	.0310532	-3.58	0.000	-.1721146	-.0502788
_cons	.2911723	.0396087	7.35	0.000	.2134709	.3688737

Variable	VIF	1/VIF
brics	7.38	0.135499
brunemp	7.00	0.142906
hidemo	6.77	0.147645
bropen	5.55	0.180091
hiunemp	4.72	0.211997
euro	2.76	0.362900
csa	2.52	0.397326
demo	2.43	0.410973
mont	2.39	0.418297
hiopen	2.27	0.440315
unfccc	2.11	0.473644
brdemo	2.02	0.495626
unemp	1.94	0.515033
afri	1.89	0.529553
swopen	1.64	0.610743
eura	1.53	0.654370
kyoto	1.41	0.709516
irtap	1.37	0.729481
noame	1.33	0.752709
midea	1.17	0.851806
Mean VIF	3.01	

VIF over 10 indicates that we have severe multicollinearity. It seems that our final model indicates no severe multicollinearity is present.

A.2 Heteroskedasticity

One of the main assumptions for the ordinary least squares regression is homogeneity of variance of residuals. If our model is well fitted, there should be no pattern to the residuals plotted against the fitted values. If the variance of the residuals is non-constant then the residual variance is said to be "heteroskedastic." There are graphical and non-graphical methods for detecting heteroskedasticity. A commonly used graphical method is to plot the residual versus fitted (predicted) values. If we observe that the pattern of data points gets narrower towards the right end it is an indication of heteroskedasticity.

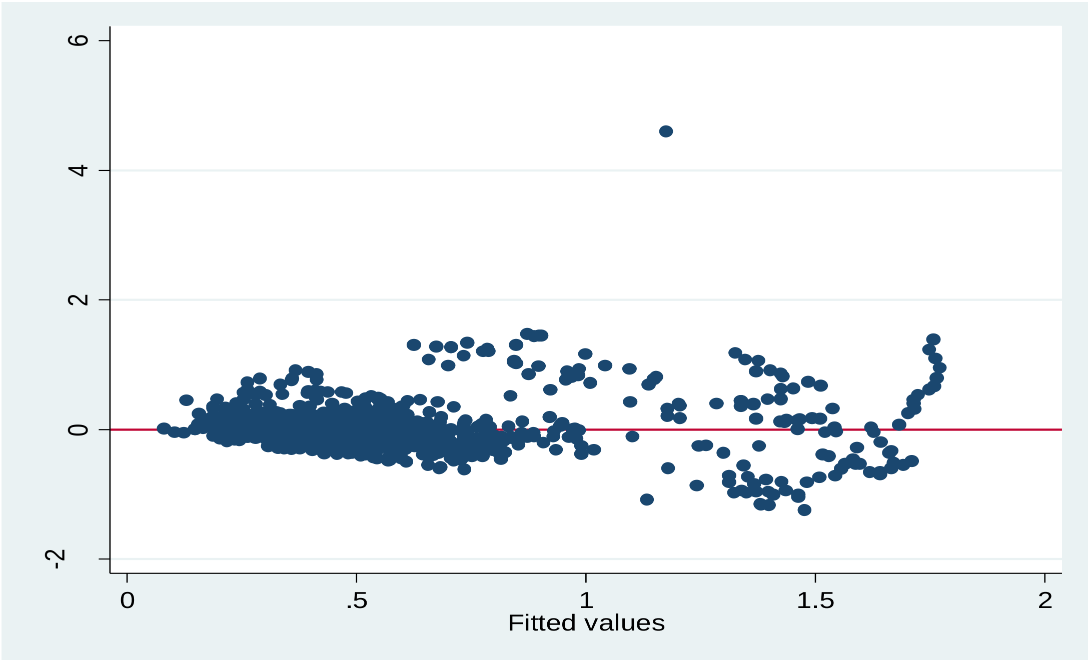


Figure A.1 residual versus fitted (predicted) values of final model

From the graph above, it is difficult to conclude that there exists heteroskedasticity for our final model. Therefore it is necessary to conduct a formal test to confirm the existence of heteroskedasticity.

Table A.2. Breusch-Pagen/Cook-Weisberg test for heteroskedasticity

```
------------------------------------------------------------------------
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
        Ho: Constant variance
        Variables: fitted values of co2gdp
        chi2(1)      =  1163.38
        Prob > chi2  =   0.0000
```

Breusch-Pagen test is a formal test to check the existence of heteroskedasticity. It tests the null hypothesis that variance of the residual is homogeneous. Hence, if the P-value is small enough, we would have to reject the null hypothesis and accept the alternative hypothesis that variance is not homogeneous. In this case, we conclude that we do have enough evidence to reject null hypothesis that the model has homoskedasticity.

A.3 Autocorrelation

First we attempt to plot the residual from our regression against time in order to check graphically whether the serial correlation exists.

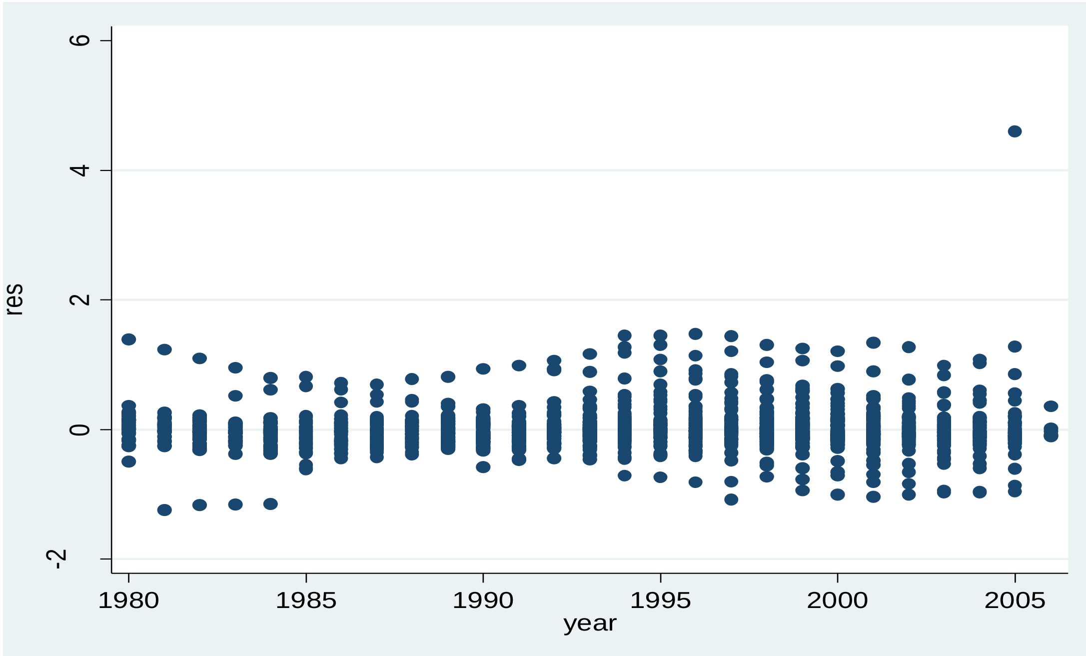


Figure A.2 Residual plot over time

Patterns of residual over time raise possibility of serial correlation. Therefore, we conduct formal test to confirm this fact.

Table A.3 Wooldridge test for autocorrelation in Panel data

```
Wooldridge test for autocorrelation in panel data
H0: no first-order autocorrelation
F(  1,     70) =    37.024
Prob > F =      0.0000
```

The null hypothesis for the Wooldridge test for autocorrelation in panel data is that there is no first order serial correlation. Therefore, we have enough evidence to reject null hypothesis that our model has no first order serial correlation.

A.4.Normality

Normality of residual is another OLS assumption that we need to check before conducting panel regression. First we take a look at density of residual.

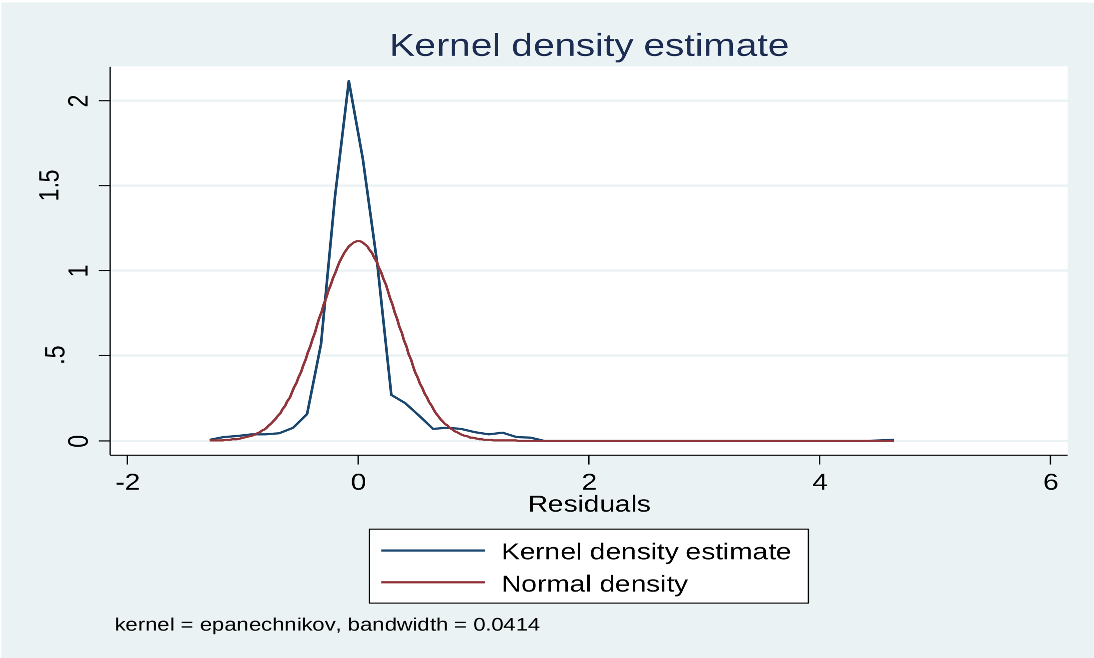


Figure A.3. Kernel density estimate

It seems like normality assumption on our model is not violated. Now let us conduct a formal test to confirm this fact.

Table A.4 Shapiro-Wilk W test for normal data

Shapiro-Wilk W test for normal data					
Variable	Obs	W	V	z	Prob>z
res	1367	0.81080	158.666	12.705	0.00000

Above is the Shapiro-Wilk W test for normality. The p-value is based on the assumption that the distribution is normal. In this case, it is small enough (0.000) to conclude that residual for the final model is normally distributed.

A.5. Stationary data

Since our data for final model is time series and cross sectional, we need to check the variables that change over time are stationary. If the variable that is included in final model are not stationary it may be necessary to take differentiation or log differentiation. We can confirm this by graphically examining relationship matrix among variables that change over time.

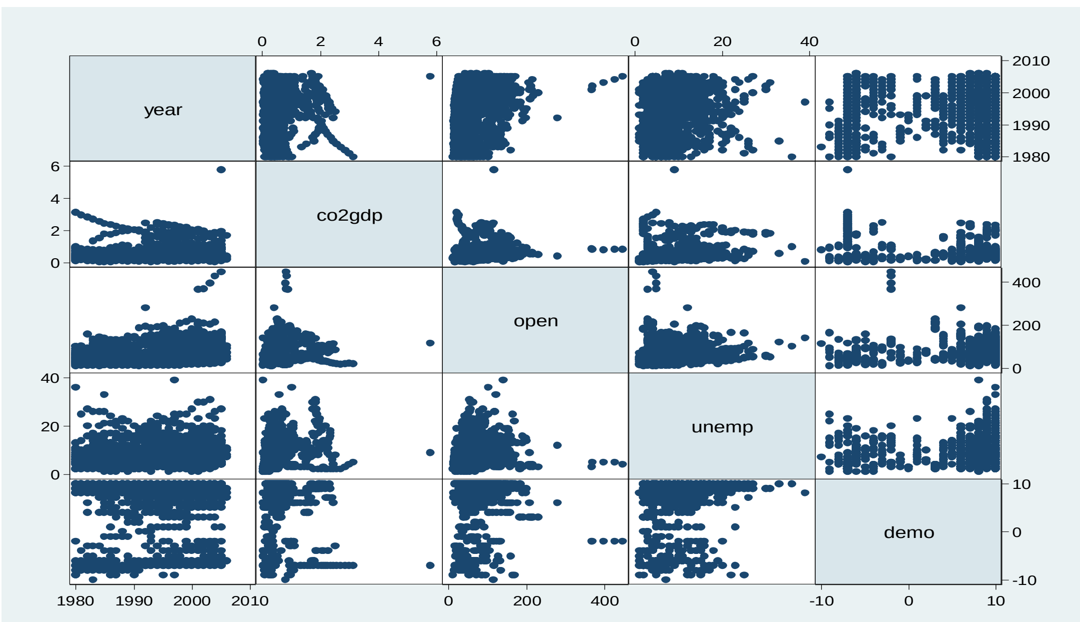


Figure A.5Variable relationship matrix

By examining the relationship matrix we confirm that variables that change over time are stationary since we do not observe any variables that consistently decrease or increase over time.

B. OLS results for chapter 3.4

Here we post our regression results for different measures of degree of openness. First, we consider the Sachs and Warner openness measure from Table B.1 to B.4.

Table B.1 OLS result between CO2/GDP and Sachs and Warner openness measure for all countries

Source	SS	df	MS
Model	15.6595995	1	15.6595995
Residual	277.310124	1365	.2031576
Total	292.969724	1366	.214472711

Number of obs =	1367
F(1, 1365) =	77.08
Prob > F =	0.0000
R-squared =	0.0535
Adj R-squared =	0.0528
Root MSE =	.45073

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
swopen	-.2804082	.0319387	-8.78	0.000	-.3430624	-.217754
_cons	.7794215	.028974	26.90	0.000	.722583	.8362599

Table B.2 OLS result between CO2/GDP and Sachs and Warner openness measure for high income countries

Source	SS	df	MS
Model	8.12276812	1	8.12276812
Residual	69.6251611	609	.11432703
Total	77.7479292	610	.127455622

Number of obs =	611
F(1, 609) =	71.05
Prob > F =	0.0000
R-squared =	0.1045
Adj R-squared =	0.1030
Root MSE =	.33812

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
swhigh	-.7010596	.083172	-8.43	0.000	-.8643984	-.5377208
_cons	1.240588	.0820068	15.13	0.000	1.079538	1.401639

Table B.3 OLS result between CO2/GDP and Sachs and Warner openness measure for non-high income countries

Source	SS	df	MS
Model	13.3721968	1	13.3721968
Residual	201.730552	754	.267547151
Total	215.102748	755	.284904303

Number of obs	756
F(1, 754)	49.98
Prob > F	0.0000
R-squared	0.0622
Adj R-squared	0.0609
Root MSE	.51725

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
swnonhigh	-.2908866	.0411455	-7.07	0.000	-.37166	-.2101132
_cons	.7445778	.0344833	21.59	0.000	.6768831	.8122725

Table B.4 OLS result between CO2/GDP and Sachs and Warner openness measure for BRICs

Source	SS	df	MS
Model	11.6507285	1	11.6507285
Residual	30.6407334	56	.547155954
Total	42.291462	57	.741955473

Number of obs	58
F(1, 56)	21.29
Prob > F	0.0000
R-squared	0.2755
Adj R-squared	0.2625
Root MSE	.7397

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
swbr	-1.04737	.2269756	-4.61	0.000	-1.502057	-.5926833
_cons	1.405227	.111514	12.60	0.000	1.181838	1.628617

Next, we consider openness measure as import and export volume divided by GDP.

Table B.5 OLS result between CO2/GDP and regular openness measure for all countries

Source	SS	df	MS
Model	7.63909655	1	7.63909655
Residual	285.330627	1365	.209033426
Total	292.969724	1366	.214472711

Number of obs	1367
F(1, 1365)	36.54
Prob > F	0.0000
R-squared	0.0261
Adj R-squared	0.0254
Root MSE	.4572

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
open	.0017672	.0002923	6.05	0.000	.0011937	.0023406
_cons	.4225057	.0242562	17.42	0.000	.3749223	.4700892

Table B.6 OLS result between CO2/GDP and regular openness measure for high income countries

Source	SS	df	MS
Model	3.94018521	1	3.94018521
Residual	73.807744	609	.121194982
Total	77.7479292	610	.127455622

Number of obs =	611
F(1, 609) =	32.51
Prob > F =	0.0000
R-squared =	0.0507
Adj R-squared =	0.0491
Root MSE =	.34813

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
hiopen	.0017244	.0003024	5.70	0.000	.0011305	.0023183
_cons	.4301081	.0266388	16.15	0.000	.3777931	.4824232

Table B.7 OLS result between CO2/GDP and regular openness measure for non-high-income

Source	SS	df	MS
Model	3.60517577	1	3.60517577
Residual	211.497573	754	.28050076
Total	215.102748	755	.284904303

Number of obs =	756
F(1, 754) =	12.85
Prob > F =	0.0004
R-squared =	0.0168
Adj R-squared =	0.0155
Root MSE =	.52962

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
nonhighopen	.0018035	.000503	3.59	0.000	.0008159	.002791
_cons	.4164546	.0395436	10.53	0.000	.3388259	.4940833

Table B.8 OLS result between CO2/GDP and regular openness measure for BRICs

Source	SS	df	MS
Model	3.82485776	1	3.82485776
Residual	38.4666042	56	.686903647
Total	42.291462	57	.741955473

Number of obs =	58
F(1, 56) =	5.57
Prob > F =	0.0218
R-squared =	0.0904
Adj R-squared =	0.0742
Root MSE =	.8288

co2gdp	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
bropen	.0139253	.0059013	2.36	0.022	.0021037	.025747
_cons	.6734663	.2303026	2.92	0.005	.2121148	1.134818

C. Fixed effect results

C.1 Base model with fixed effect

Since we find both heterskedasticity and autocorrelation for our panel data set we use Drisoll-Kraay standard errors to correct both so as to obtain consistent and robust result for panel regression with fixed effect. Driscoll and Kraay standard errors are the standard errors that are heteroskedasticity consistent and robust to cross-sectional as well as temporal dependence.

The regression result is as follow.

Table C.1 Base Model with Fixed effect

```
Regression with Driscoll-Kraay standard errors   Number of obs     =      1367
Method: Fixed-effects regression                 Number of groups  =        98
Group variable (i): coun_new                     F(  4,     97)    =      8.32
maximum lag: 1                                   Prob > F          =    0.0000
                                                 within R-squared  =    0.0499
```

co2gdp	Coef.	Drisc/Kraay Std. Err.	t	P>|t|	[95% Conf.	Interval]
demo	.0031652	.0010568	3.00	0.003	.0010678	.0052625
unemp	.0003686	.0015423	0.24	0.812	-.0026925	.0034296
open	-.0017944	.0004056	-4.42	0.000	-.0025995	-.0009894
swopen	.0891295	.0241672	3.69	0.000	.0411643	.1370947
_cons	.5794826	.0258097	22.45	0.000	.5282575	.6307077

C.2 Final model with fixed effect

Here again we use Driscoll and Kraay standard errors to control both heteroskedasticiy and a serial correlation. The regression result is as follow.

Table C.2 Final model with fixed effect

```
Regression with Driscoll-Kraay standard errors   Number of obs     =      1367
Method: Fixed-effects regression                 Number of groups  =        98
Group variable (i): coun_new                     F( 13,     97)    =     52.41
maximum lag: 1                                   Prob > F          =    0.0000
                                                 within R-squared  =    0.2612
```

co2gdp	Coef.	Drisc/Kraay Std. Err.	t	P>|t|	[95% Conf.	Interval]
brunemp	-.0219333	.028152	-0.78	0.438	-.0778073	.0339407
brdemo	.0063333	.0078136	0.81	0.420	-.0091745	.0218412
bropen	-.0231948	.0072302	-3.21	0.002	-.0375448	-.0088449
hiunemp	.0047926	.0029447	1.63	0.107	-.0010517	.010637
hidemo	.0929142	.0375295	2.48	0.015	.0184285	.1673999
hiopen	-.0018401	.0006402	-2.87	0.005	-.0031108	-.0005694
demo	.0022721	.0011208	2.03	0.045	.0000476	.0044967
irtap	-.0829731	.0724663	-1.14	0.255	-.2267986	.0608524
mont	-.0033863	.0128611	-0.26	0.793	-.0289121	.0221395
unfccc	-.0375966	.0170626	-2.20	0.030	-.0714612	-.003732
kyoto	-.0225368	.0109714	-2.05	0.043	-.0443121	-.0007616
unemp	-.0010796	.0012051	-0.90	0.373	-.0034714	.0013121
swopen	.117783	.0249782	4.72	0.000	.0682082	.1673579
_cons	.1823653	.1796146	1.02	0.312	-.1741199	.5388505

D. F test for interaction terms

D.1. Interaction with high income countries

```
 ( 1)  hiunemp = 0
 ( 2)  hidemo = 0
 ( 3)  hiopen = 0

       F(  3,  1346) =   25.81
            Prob > F =    0.0000
```

We have enough evidence to reject null hypothesis that interaction variables with high income countries dummy are all 0.

D.2. Interaction with BRICs

```
 ( 1)  brunemp = 0
 ( 2)  brdemo = 0
 ( 3)  bropen = 0

       F(  3,  1346) =   60.48
            Prob > F =    0.0000
```

We have enough evidence to reject null hypothesis that interaction variables with BRICs dummy are all 0.

D.3. All interaction variables

```
 ( 1)  brunemp = 0
 ( 2)  brdemo = 0
 ( 3)  bropen = 0
 ( 4)  hiunemp = 0
 ( 5)  hidemo = 0
 ( 6)  hiopen = 0

       F(  6,  1346) =   44.32
            Prob > F =    0.0000
```

We have enough evidence to reject null hypothesis that interaction variables with BRICs dummy are all 0.

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